THE STORY OF PLANTS

Scene in a tropical rain forest jungle

The Story of Plants

BY JOHN ASCH

ILLUSTRATED BY
TABEA HOFMANN

G. P. PUTNAM'S SONS

To my mother, who imparted to me her love of plants, and my wife, who collaborated closely with me during the entire course of the work and typed the manuscript

MANUFACTURED IN THE UNITED STATES OF AMERICA

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FOREWORD

I have tried to present in this single volume a summary of the important features of plant life, described in nontechnical language that a person with little or no knowledge of botany and related subjects can understand without consulting a glossary or dictionary.

In preparing the material and illustrations, I have consulted hundreds of technical and popular periodicals, bulletins, and books, and visited scientific and commercial agricultural establishments in nearly every state of the United States, many of the countries of Europe, and those bordering the Mediterranean Sea. My practical experience comes from over twenty years of study and work with plant life in many lands.

The illustrations were suggested by the author and executed by Miss Tabea Hofmann. Whenever feasible, plants and plant parts were drawn from nature or directly from prepared material examined through the microscope. Other drawings and charts were inspired by the author's and artist's imaginations; by English, Spanish, French, and German natural histories and botanies of the nineteenth century; by scientific papers in which the desired subjects were originally described and illustrated; and by the author's personal photographs and his extensive picture-post-card collection.

It is impossible to undertake and complete such a work as this without the helpful assistance and inspiration given by numerous people interested in plant life. Grateful thanks are extended to the librarians and other members of the staffs of the United States Department of Agriculture; the several state agricultural colleges and experiment stations; the Citrus Experiment Station of the University of California, at Riverside, California; the Carnegie Institute at Washington, D.C.; the Natural History Museum of New York; Miss Elizabeth C. Hall, Librarian, New York Botanical Gardens, Bronx Park, New York; Mr. William C. Jordan, Librarian, Brooklyn Botanic Gardens; Columbia University, New York; Massachusetts Horticultural Society, Boston, Mass.; New York Horticultural Society, New York City; New York Public Library; the Smithsonian Institute, Washington, D.C.; Pierpont Morgan Library, New York; Jardin des Plantes, Paris, France; Botanic Gardens of the

University of Montpellier, France; agricultural schools and experiment stations in Syria, Portugal, Palestine, Algeria, and Morocco. And last but not least the National Farm School, Doylestown, Pennsylvania, where the author was initiated into the world of plant life.

Professor M. A. Johnson, of the Department of Botany, Rutgers University, critically read the entire manuscript. His valuable suggestions are gratefully acknowledged.

JOHN ASCH

Part I: Life

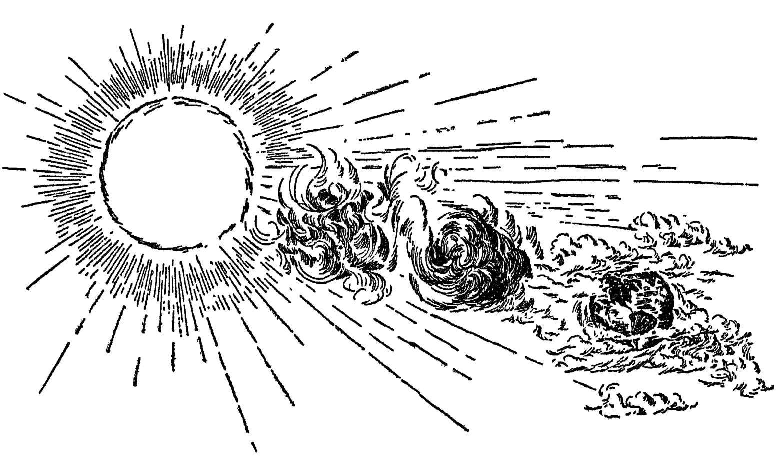


Fig. 1. The birth and evolution of the earth

1. THE SUN AND THE EARTH

FROM the very beginning of human life, man has known hunger and the need for food. The history of man's world has been his struggle for the daily bread that is his first and most pressing need. Thus plants have a fundamental importance to us. But very few of us stop to think that they provide us with more than food alone.

From some parts of plants come objects that we use daily. For example, the chairs we sit on, the clothes we wear, the canvas and colors of magnificent paintings we admire, the rugs we walk on; all our plastics, nylon, rayons, silks; the paper, ink, and binding from which this book is made; rubber, gum, all oils, and many other items too numerous to mention. Coal and petroleum, the source of many products we use, are residues of vegetation that grew on this earth millions of years ago.

Without plant growth there would be no humans, animals, birds, fish, or insects. These eat plants directly or feed on animals that live on vegetation and change it into milk, eggs, meat, leather, fur, wool, silk, and honey.

Furthermore, this earth would be a sad and dreary place indeed without the delights that the plant world gives us. Even if we did not need plants to support all life on earth, for our food, shelter, clothing, and many other necessities of our modern day-to-day life, without them we would lack many pleasures and beauties. Try to imagine our cities

without parks, our land without trees, our homes without lawns and gardens, the countryside void of greenery, naked and uninviting, with no colors, no flowers, no fragrant perfumes, just a dismal sameness everywhere.

Anything so vital to our very existence is obviously worth our interest. But before we venture into the fascinating world of plants, we should know how our earth was formed and how life is possible on our planet.

Our earth had its beginnings from over ninety different, intensely hot, churning gases that were thrown out from the sun into space where they began to spin around the sun on a definite path. As these gases twirled around, they were pressed together into the form of a ball, and they started to cool (Fig. 1). In cooling they became a molten mass that attracted to itself all the free particles of material flying about near by. As these particles of matter were united with the molten soft globe, the earth became bigger and bigger until it reached its present size. It still attracts particles, which are called meteorites, and we are being constantly showered with them to this day. Most meteorites are tiny specks, but once in a while huge lumps weighing several tons fall to earth, shaking the surrounding countryside.

In chilling, some of the original gases became liquids. Still later they started to combine with one another. On further cooling, others became solids. As the earth continued to cool and shrink, the hard outer portion was raised in some places and lowered in others, forming an uneven, folded, and wrinkled surface. It was in this way that our earth's original hard rocky crust was slowly formed. These processes took many millions of years.

By the time the rocks were formed, our earth had become cool enough to be able to form clouds from some of the gases that were left free, and from these clouds the world was deluged with torrential rains. The enormous quantities of water cut the softer rock formations, creating gullies and rivers. The waters filled up all the low places on the earth's uneven surface, forming lakes, seas, and oceans. The higher, exposed portions were ground down by destructive agents such as winds, frosts, rains, and waves. The loosened rock particles were carried by rivers and torrents to the seas and lakes, where they were deposited as layers of mud. Each new layer of sediment helped to press down and harden the previously deposited layers of mud. Eventually heavy rocks were formed that pressed down and lowered the sea floor, causing various kinds of strains and stresses that resulted in earthquakes, upheavals, volcanic eruptions, and other movements that raised new sections and lowered others. The raised portions were ground down in turn, and deposited over the older rocks. These events have been taking place throughout geological time, occur all over the world today, and will

presumably continue as long as the earth in its present form exists. The expression "Everything that goes up must come down" holds for mountains, too.

Somewhere, somehow, when the rocks were properly ground up, when the waters were cool enough, when all the conditions for life were present, the first living thing appeared on earth.

Our earth is an offspring of the sun. As a heritage it received over ninety gases, which we call elements. Our entire earth and everything that is in it—on its surface or in its atmosphere—consist of one or a combination of two or more of these original gases.

Our sun not only gave us this rich legacy, but also takes good care of its child. It gives us light and warmth, and, most important of all, supplies us with energy. All the energy we use, whether it is in moving our muscles in our daily tasks, in thinking, or in using any of our senses; all the energy we use in our machines, in transporting us or our goods, in lighting and heating; all the power we use in manufacturing and processing originated in our sun. And practically all of it is fixed by plants for our use.

Fig. 2. All these have one thing in common: they are all living organisms.

2. LIFE

ALL things on our earth, in fact all things in the entire universe, are divided into two main groups—they are alive, or they are not. Life is the puzzle of the universe, and we know very little about it. We do know that there is no special element of life, and therefore there is no impassable barrier between living things and lifeless objects. They are not so vastly separated as they seem to be.

When we hold a seed in our hands, an acorn, for instance, it does not look alive. It is hard to imagine that within it are all the growth characteristics to produce a huge oak tree over a hundred feet tall, with an extended root system and tens of thousands of leaves, which will in turn bear a multitude of acorns in its many years of life. The force of life and the mystical power of growth are embodied within the hard shell.

Living organisms are only temporary homes of substances and energies whose ceaseless change is difficult to visualize. A fountain looks like a persisting individual thing, yet the drops of water of which it is made are never the same from one second to the next. It could not exist if new drops of water did not continually come out of the openings to replace the ones that have already fallen into the basin.

Life, like the fountain, is never finished. It is always being renewed. All living things are at each instant continuously being broken down and built up. Living organisms select and absorb certain elements, constantly change them, assemble them, and manufacture living cells. The person we know and the plant we see are very special and unique individual living things. The particular substances that are gathered and working in that being will never be together again after the individual dies. They have been captured by that living structure and are forced to follow the natural laws of that particular person, animal, or plant. After the death of the organism, the elements are released to continue through constantly changing cycles in nature.

All living things are organisms made up of a cell or cells, one cell in the simple bacteria, multitudes of different kinds of cells—many billions of them—in the individual living human (Fig. 2). All cells have the same properties, and those are the qualities of life itself. Individual cells as well as all forms of life that are made up of groups of cells are so different that only to describe their external forms, interior structure, and types of activities is the subject of many sciences. When we visit museums of natural history, zoos, fields, and gardens, we see tens of thousands of different forms of life. No two blades of grass, no two leaves, no two grains of wheat are exactly alike.

We can tell that something has life when it shows certain characteristics. All living things exhibit these whether they are tiny microscopic spores, cells, hard seeds, trees, whales, sponges, mushrooms, horses, chickens, or humans.

First and foremost is the fact that all living things have a parentage. We have no idea where the parentage came from, how it came to be. Every living thing, whether a giant tree, an elephant, or a human being, was a tiny invisible cell at the beginning of its existence. This cell was either a special outgrowth from one very low form of life or the result of the combining of two gametes from two different parents. Growth took place because the original cell grew; then, after it reached a certain size and age, it divided itself into two, these two became four, the four became eight, and so on until the organism reached full maturity.

All living things can adapt themselves to varying outside conditions, which we call environment. In nature the maximum growth possible in any given environment is always present. When some factor in an environment makes life in any form impossible, we find a bare spot. Our earth possesses a continuous surface upon which organisms live. This surface, as we know, is not at all uniform. We have flatlands, deserts, prairies, mountains, hard rock formations, rivers, lakes, salty seas, and oceans. Each has its own particular form of life, which has adapted itself to that environment. Water lilies thrive in sweet water; seaweeds and many forms of life live in the salty oceans; cacti prosper in hot, dry desert areas; edelweiss grows on high snow-covered mountains; the maple almost stops all activity during the cold winter months and sleeps—this we call a dormant state—until the warm spring wakes it up. Seeds are miniature plants in a dormant condition waiting for the opportune time and place to start growing. A seed is very much alive.

All living things take in materials from the outside. They absorb water. They take in various substances. They accumulate foodstuffs to make up their structures. They use energy in growing and moving. They also are able to distribute the food, air, and water to each and every cell however far away from the original point of entry.

Every organism that takes in nourishment and uses various materials for its activity and growth must be able to eliminate waste substances that would otherwise form poisons in the system.

All things that live take in certain gases from the atmosphere, use and change them, then return them to the air. The farthest root deep down in the ground lives in a special atmosphere and uses the gases that are there.

To a certain degree all living things move. Plants move their leaves and stems, sway with the wind, and some of them fold and unfold their flowers and leaves. Although most individual plants do not move from their place of growth themselves, they disperse their seeds far and wide and establish their offspring at great distances from the mother plant.

Protective layers and systems are developed by all living things. Animals have fur, sharp teeth, and horns. Trees have cork and bark. Some plants have gums that cover wounds, many have spurs sharp as needles, others have vile-smelling and poisonous substances.

The last and perhaps the most important characteristic of living things is the fact that they are all able to reproduce themselves and multiply. If this were not so, the earth would be barren. All life could endure only for one generation.

Every living thing, in multiplying, tends to occupy larger and larger areas because it is the universal law that there be the maximum possible growth present. This extension is limited by competition offered by other forms of life and also by the environment.

For there to be life in any form, certain conditions are essential. We know that parentage is absolutely necessary; that the organism must adapt itself to external conditions; that all living things must take in materials from the outside, and must be able to distribute them to each and every cell; that they must be able to take in and use oxygen; that they are able to move to a certain degree; that they have to have protective tissues; and last and of great importance, that they must be able to reproduce themselves and multiply.

In order that all these processes may take place, many favorable conditions must exist. When all the conditions are satisfactory, we have what we call optimum or perfectly balanced and unlimited life processes taking place. Fortunately, there is a balance in nature.

All living things can exist only in an environment that provides at least the minimum and at most the maximum of everything they need. If there is a lack of any single essential, or if there is too much of it, that one circumstance is enough to upset the balance of life. Death will result even if all other requirements are met. The factor that is lacking and therefore below the minimum need, or the one there is too much of and has passed the maximum the organism can stand, is called the

limiting factor (Fig. 3). Too little or too much water, not enough or too brilliant sunshine, too much or too little nitrogen are limiting factors. Intense heat is as killing as deathly frost. An overabundance of anything kills life. Likewise, a minimum amount of everything necessary must be available if life is to continue.

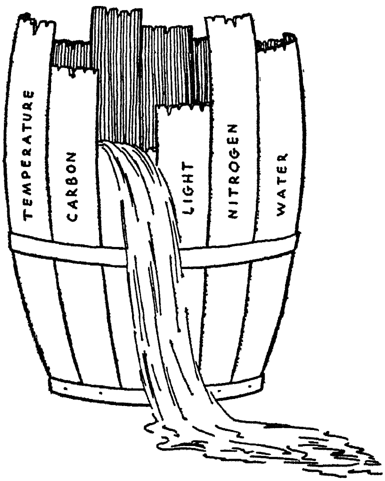


Fig. 3. Limiting factors

In the unrelenting struggle for existence among the different forms of life, each kind tries to eliminate the others and take possession of all the space, food, and water for itself. Balance in nature is achieved because at the moment when one form is on the verge of dominating others, some limiting factor curtails that growth. Larger animals that multiply slowly eat smaller ones that breed rapidly. Vegetation that is too thick chokes and starves itself by using up all the available space. If this were not so the sea would be solid fish. The atmosphere would be so full of germs, insects, and birds that there would be no light or air at all. The ground would be choked up with one winning form of life.

So far we have dealt with all manner of living things, both animal and vegetable. Now we shall draw our dividing line between them. The most important difference between the vegetable and animal kingdoms is that plants are able to take the gases from the air and combine them with water to form their own basic food by using the energy that comes in the form of light from the sun. As a general rule animals must eat plants or other animals that feed on plants in order to live.

All the higher forms of green plants have groups of special dividing cells that are localized at definite growing points, in buds, and at the ends of stems and roots. These dividing cells retain their power of forming new cells indefinitely, so such plants never stop forming new cells and growing as long as they are alive. Animals are able to grow only during their youth, and they stop growing when they reach the size that is characteristic of their kind.

While most animals have bonelike skeletons around which softer tissues and organs are placed, most plants have no inner skeleton. Plant cells have instead thick sustaining walls called cellulose. We manufacture our paper, linen, cotton, twine, and cord from them.

NUMBER OF ELECTRONS IN OUTER LAYER → = NUMBER OF SHELLS ↓	GROUP I	GROUP II	GROUP III	GROUP IV	GROUP V	GROUP VI	GROUP VII	GROUP VIII TRIAD ELEMENTS	GROUP VIII INERT GASES
1.	HYDROGEN 1 H-1								HELIUM 4 He-2
2.	LITHIUM 7 Li-3	BERYLLIUM 9 Be-4	BORON 11 B-5	CARBON 12 C-6	NITROGEN 14 N-7	OXYGEN 16 O-8	FLUORINE 19 F-9		NEON 20 Ne-10
3.	SODIUM 23 Na-11	MAGNESIUM 24 Mg-12	ALUMINUM 27 Al-13	SILICON 28 Si-14	PHOSPHORUS 31 P-15	SULPHUR 32 S-16	CHLORINE 35 Cl-17		ARGON 40 A-18
4.	POTASSIUM 39 K-19	CALCIUM 40 Ca-20	SCANDIUM 45 Sc-21	TITANIUM 48 Ti-22	VANADIUM 51 V-23	CHROMIUM 52 Cr-24	MANGANESE 55 Mn-25	IRON 56 Fe-26; COBALT 59 Co-27; NICKEL 58 Ni-28	
	COPPER 63 Cu-29	ZINC 65 Zn-30	GALLIUM 70 Ga-31	GERMANIUM 73 Ge-32	ARSENIC 75 As-33	SELANIUM 79 Se-34	BROMINE 80 Br-35		KRYPTON 84 Kr-36
5.	RUBIDIUM 85 Rb-37	STRONTIUM 88 Sr-38	YTTRIUM 89 Y-39	ZIRCONIUM 91 Zr-40	COLUMBIUM 93 Cb-41	MOLYBDENUM 96 Mo-42	TECHNETIUM 98? Tc-43	RUTHENIUM 102 Ru-44; RHODIUM 103 Rh-45; PALLADIUM 107 Pd-46	
	SILVER 108 Ag-47	CADMIUM 112 Cd-48	INDIUM 115 In-49	TIN 119 Sn-50	ANTIMONY 122 Sb-51	TELLURIUM 128 Te-52	IODINE 127 I-53		XENON 131 Xe-54
6	CESIUM 133 Cs-55	BARIUM 137 Ba-56	RARE EARTHS 57-71 139-175	HAFNIUM 179 Hf-72	TANTALUM 181 Ta-73	TUNGSTEN 184 W-74	RHENIUM 186 Re-75	OSMIUM 190 Os-76; IRIDIUM 193 Ir-72; PLATINUM 195 Pt-78	
	GOLD 197 Au-79	MERCURY 201 Hg-80	THALLIUM 204 Tl-81	LEAD 207 Pb-82	BISMUTH 209 Bi-83	POLONIUM 210 Po-84	ASTATINE 220? At-85		RADON 222 Rn-86
7.	FRANCIUM 224? Fr-87	RADIUM 226 Ra-88	ACTINIUM 229 Ac-89	THORIUM 232 Th-90	PROTOACTINIUM 231 Pa-91	URANIUM 238 U-92			

Fig. 4. Atomic chart of the known natural elements. The ten heavily outlined elements are found in considerable quantities in all plants.

3. THE ATOM

WHEN a fact of nature is discovered it can be stated clearly in a few simple words. If it proves always to be true, a law of nature has been revealed to us. This is not a law that we have made, but a forecast that has proved correct every time it was tested.

Whenever we touch a red-hot piece of metal we shall be burned. A glass of milk weighs much less than the same glass full of sand, so we know that sand weighs more than milk. As you see, laws of nature are used all the time in our day-to-day lives.

Many scientists are continuously studying different kinds of substances and events. Their ideas and thoughts—in other words, hypotheses—are written down and tested. Those that cover most of the probabilities are published as theories so that other scientists can try many experiments under varying conditions. When it is found that a theory or a group of theories answers all the questions pertaining to a particular field of study, a law of nature has been uncovered. It is stated in simple language or as a mathematical formula that anyone interested can understand and use.

Hypotheses and theories, no matter how remote they may be from the truth, are very helpful. They are used until better ones are thought of, tested, and proved. It must always be remembered that these, and even laws of nature, are not final truths. Sometimes another law is later discovered that takes in the known one. A more complete and enveloping truth is constantly being sought. Many scientists believe that someday all matter, energy, and life will be explained in one universal law.

According to modern ideas, all matter is made up of atoms having a few fundamental parts. As atoms are so very small, no one has ever seen them. In fact, they are so tiny that millions of them are necessary to make the dot on this i. It is therefore very difficult to visualize them clearly.

From the dawn of civilization to the present day scientists of different lands have developed certain theories about atoms. Today we have only a very vague idea as to the way they are made, how they combine to form all the substances we have on this earth, and the manner in

which the energy locked up in them is transformed for daily use. The final law dealing with their construction and behavior has not yet been discovered. The present-day theories do not explain everything that takes place. However, many things that happen fit into the picture that has been so far formed. In spite of the fact that nobody has seen any atoms, learned men have been able to observe, and in many cases foretell, some of the things that atoms can do.

Let us imagine that we are watching some shadows on a wall while the objects causing them are hidden from our view. We shall say that a boy is playing with his dog. From the shadow of his clothing, movements, and manners we can tell that he is a boy. We can determine whether the dog is big or small, playful or quiet. If other people approach, we can tell whether they are children or grownups, male or female, friends or enemies. From watching the various shapes and antics of the shadows, we can deduce many things. In a similar manner many objects that cannot be seen are studied by their effects on things that can be seen or photographed or can, by the use of special instruments, be heard, measured, or weighed.

Many hundreds of years ago Greek scientists noticed that when they rubbed a piece of amber on wool, the amber received some mystical power enabling it to attract small pieces of paper. We can try this ourselves by rubbing a fountain pen on our clothing. As amber in Greek is called *elektron,* this mystical something has been called electricity to this day. We also know that when a rod of glass is rubbed on silk, we bring forth another kind of electricity that has the opposite effect of that of amber. Whereas amber will attract, glass will repel. In order to simplify descriptions, one is called positive electricity, the other negative. It has been found that everything, whether a particle of soil, water, gas, air, metal, or living tissue, is made up of electricity. We do not know what electricity is. We only know a few things that we can do with this phenomenon of nature. Electricity is not created. It is the essence of all matter.

When a thing having positive electricity is brought in contact with an object that has the same kind of electricity, they will repel one another. Likewise negative will repel negative. But when positive approaches negative, they attract one another. If both are of equal strength, the object will be neutral and not show any electrical property at all. Plus and plus repel, minus and minus repel, plus and minus attract and form neutral. Therefore, all matter is made up of atoms having positive, negative, and neutral electrical qualities.

So far as has been learned until now, an atom has been visualized as something similar to a tiny universe. This so small system of vibrating, throbbing, quivering electricity is composed of several parts (Figs. 4, 5).

In the center there is a nucleus. This nucleus, the core of the atom, is made up of very tiny, exceedingly heavy particles of both positive and neutral electricity; indeed, it contains practically the entire weight and mass of the atom. It is so small that if all the nuclei of all the atoms of the entire earth were brought together in a ball, the ball would be only the size of an orange! It is so heavy that a thimbleful of nuclei would weigh a million tons.

The positive electrical particles in the nucleus are called protons. It has been found that the atoms of the lightest known element, hydrogen, have just one proton in their nuclei. Progressively, one by one, as more protons are present in the nuclei of atoms, all the known elements are formed. The heaviest known natural atom on the list, uranium, has ninety-two.

There are also present in the nuclei of practically all elements tiny heavy particles called neutrons, which give added weight to the element. It is believed that they are made of positive and negative electrical particles tightly wedged together.

All elements, with the probable exception of hydrogen, are believed to contain neutrons, but the number may vary from atom to atom of the same element. The neutrons do not change the chemical properties of the element. Each variety or kind of atom as determined by the number of its neutrons is called an isotope of that element. For instance, the element tin has eleven kinds of atoms. Each of these has a varying number of neutrons, but always the same number of protons, and therefore the same chemical characteristics.

We now come to the very important electrons. A great deal has been written and spoken about these small, very light particles of negative electricity. They are of vital importance, as they are the key to the arrangement of all matter. Electrons are arranged in layers or shells. They vibrate, move, and fly around the nucleus somewhat as our earth and sister planets travel around the sun. If we were to enlarge the nucleus to the size of a pea, the nearest electron in an atom would be a balloon three hundred miles away and about sixty feet in diameter. All electrons are alike. It is the difference in their number and placement around the nucleus that account for all the different kinds of substances we have on this earth and in the entire universe.

In the perfectly balanced neutral atom, there are exactly the same number of electrons as protons. As hydrogen has one positive proton, it has one negative electron. Carbon has six protons and six electrons. Uranium has ninety-two protons and ninety-two electrons.

No matter how many negative electrons are needed to neutralize the positive protons, the first or innermost layer never has more than two. Helium, which has just two electrons, is complete and chemically inactive. Regardless of the number of electrons that may be pres-

ent in a given element, the outer shell is always complete when there are eight electrons. Neon, argon, and the other atoms that have eight electrons in their outer shells are complete and remain aloof from other elements. Like helium, they are called inert gases and do not generally enter into chemical combinations.

All the atoms the outer shells of which contain from one to seven electrons are not complete. They are chemically active and try to complete their outer shells by sharing, lending, borrowing, or giving their electrons. This is why there are so many hundreds of thousands of chemical combinations that are forever being built up and broken down. For instance, sodium, which has only one electron in its outer shell, will readily combine with chlorine, which has seven, therefore lacking one. They make a very strong union that becomes the common table salt we use with our food (Fig. 5).

Since positive electricity attracts negative, the electrons are attracted to the nucleus. If it weren't for their active motion, they would fall into the nucleus. The outer electrons, being held by a weaker force, are easily separated from the atom. This removal does not change the element, because the required number of protons are still present. Only the electrical properties have become unbalanced. Such electrically unbalanced atoms are called ions. When an electron is lost, the ion has one more unit of positive electricity. When this electron attaches itself to the outer shell of another atom, that one becomes a negative ion. If two or more electrons are removed or added, the positive or negative electrical forces of the ion are that much stronger. Later, these temporary electrons may leave the negative ions, and free electrons may attach themselves to positive ions, thereby returning them to their original state as neutral atoms. In liquids ions may move about from one substance to another with great ease without losing their identity. It is in the form of ions that many elements enter and are used in plants.

Some atoms are very complicated. They have many electrons arranged in several layers or shells. Every once in a while, for some mysterious reason, an electron will jump from one layer to another. When electrons leap from an inner layer to an outer one, they release energy that can be detected. Other atoms, like radium, continuously throw off electrons, rearrange their protons and neutrons, and release some of them in such a way that they eventually change into other elements. These are called radioactive atoms. Scientists have recently been able to produce this activity artificially in many kinds of atoms. This energy can be controlled and is used in medicine and scientific investigations of living matter of all kinds. Many mysteries of nature will be uncovered by this process.

An element is a chemical substance containing only one kind of matter, all the elements of which have the same number of protons. In

other words, an atom is the smallest ultimate particle of an element, and all the elements are built up of atoms, each element of its own kind of atom. The atoms of the different elements differ in the number of protons they contain, and when broken up they lose their identity.

Atoms which have incomplete outer shells have a tendency to cling together in pairs or in larger groups in regular ways, and these groups once formed tend to persist. These larger groups are called molecules. Every chemical compound is made up of characteristic atoms arranged in a definite pattern.

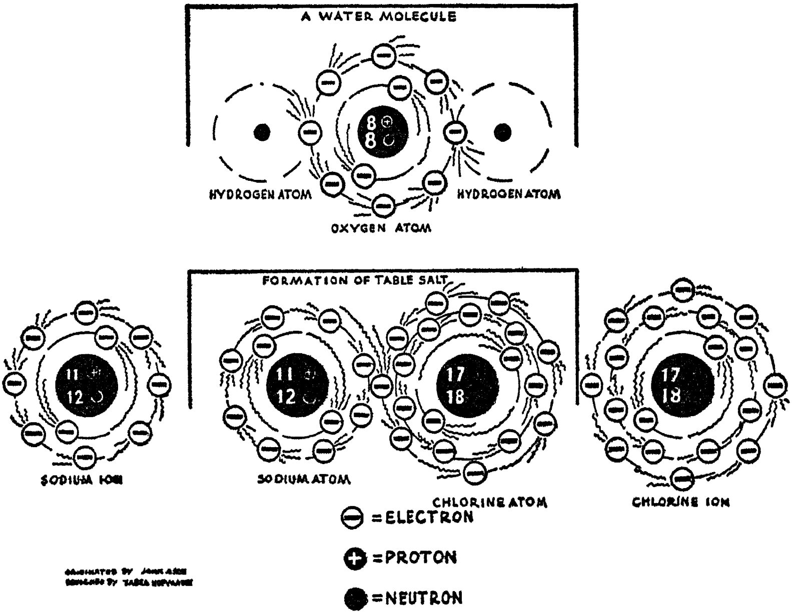


Fig. 5. Water and table-salt molecules. One oxygen atom combines with two hydrogen atoms to form one water molecule. One chloride and one sodium atom combine to form a molecule of table salt.

4. STRANGE THINGS TAKE PLACE

IN nature, atoms and ions are usually found in combinations with one another. In other words, atoms and atoms, ions and ions, or atoms and ions can combine. Very seldom and only under unusual circumstances will they be alone. Therefore, the smallest particle of a substance, which is called a molecule, is the combination of two or more atoms. Electrical charges are very important in determining the structural arrangement and stability of these molecules.

The number of atoms or ions in a molecule may be very small or tremendous. One molecule of water has only one atom of oxygen and two of hydrogen. The casein molecule of milk has a total of 2,150 atoms. Some molecules, like rubber, have several tens of thousands, even hundreds of thousands, of atoms and ions in their structures. One of the reasons why the study of living organisms is so difficult and has progressed so slowly, is that there are present such large numbers of atoms in living matter.

Appearances and properties of substances depend not only on the numbers and kinds of elements present, but also upon their arrangement within the molecules of the compound. The element carbon, which has four outer electrons that it can share, enters into hundreds of thousands of combinations with hydrogen and oxygen. Coal, oils, fats, paper, sugar, starch, and many other things are a result of the endless variations and unions into which these three elements can combine. Just as we use only twenty-six letters in our alphabet to make up all the words in our language, so the combinations and proportions of the ninety-two known elements make up everything on earth. The letters PTA arranged one way give us the word "pat" but we can rearrange them to form "tap" or "apt." (Figs. 6, 9, 14, 15, 16, 17.)

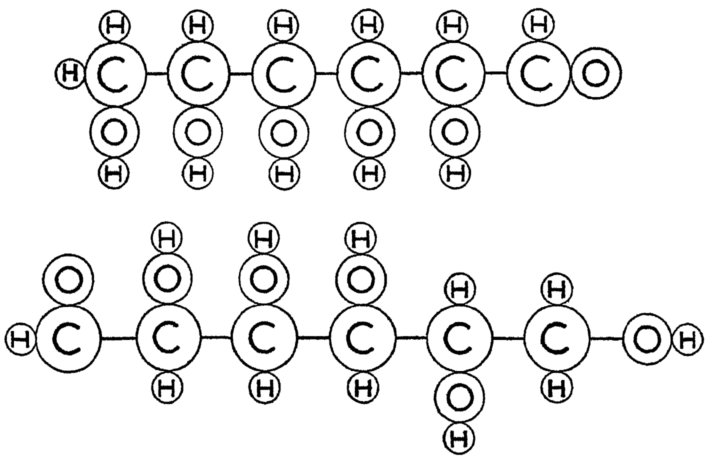


Fig. 6. Two ways in which 6 oxygen, 6 carbon, and 12 hydrogen atoms may arrange themselves in chains to form carbohydrate molecules

Like the electrons of the atoms, molecules constantly move and vibrate at terrific speeds. The speed with which they move depends mainly on the pressure that is exerted and their temperature. At ordinary room temperature, oxygen is a gas, water is a liquid, and iron is a solid. At absolute zero, which is about 460 degrees below zero on the Fahrenheit scale, the electrons, and therefore the atoms and molecules, are at a standstill. Above this temperature, the different elements and their combinations exist in various forms depending upon their nature. As heat is added, the activity of the electrons is accelerated and the solid melts, becoming a liquid. When the temperature is high enough, the molecules liberate themselves from their neighbors and fly out as particles of gas. This is exactly what happens when water is heated to

the boiling point and evaporates. On the other hand, when heat is removed, the electrons are slowed up and a liquid or a solid is formed.

In a solid, the electrons are held very close together so the object is hard and has definite shape and form. A semisolid, like butter, is soft and can be pressed into a form. In a liquid, each molecule clings to its neighbor and the fluid conforms to the shape of the container in which it is placed.

In a gas, the molecules are free and bounce around at will, spreading themselves out until they fill up all available space. Heat will expand, cold will contract, and pressure will press them closer together. At a certain temperature and pressure there will always be a definite number of molecules of gas in a given space. A hundred molecules in a room will spread themselves evenly all over the space; so will a hundred billion. There will not be more in one place than in another. Their speed is about a mile per second. However, as their jump is only one two-hundred-thousandth of an inch and they are so small and elastic, they do not harm each other.

We are able to smell the perfumes of flowers, new-mown hay, aromatic herbs, and many other objects, both pleasant and unpleasant, when standing at some distance from them, because the molecules of these travel about in the air. They enter our noses, stimulating certain special nerve fibers that lead directly to the brain. The more molecules the substance releases, the stronger the scent.

When molecules of matter are lying separately in a liquid or gas, we say that they are in suspension. They can be easily removed by the use of a screen or filter. When such a substance is lighter than the liquid, it will rise to the top by itself, as cream does in milk. If heavier, it will fall to the bottom, as sand does in water.

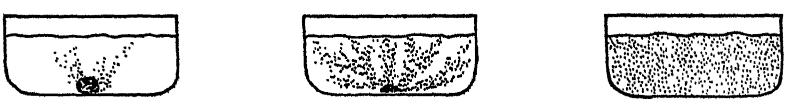


Fig. 7. Crystal dissolving in a liquid

Sugar in water will completely disperse its molecules, forming a sweet solution. Although the molecules of sugar and water are separate, they constantly move about, bump into each other, and spread out evenly throughout the fluid. They cannot be separated by mechanical filters because the two have intermingled. We say that a substance is in solution when it can so disperse in a liquid (Fig. 7). Matter can enter and move within plants only when it is in a solution. After a certain substance has entered the plant, it can be fixed in place as stored food or can build up the plant structure by being made insolvent. When the occasion arises, the stored food can be changed back to a soluble form so

that it can be moved and used. This is one of the main activities of all living organisms, human and animal as well as plant, and is called digestion.

When different substances like pepper and salt, or lime and sand, are placed together, we say that we have a mechanical mixture. The molecules, although close together, do not enter into chemical combinations.

A chemical reaction is a partial or total transfer of electrons from one atom to another. We can classify all chemical changes into four general groups.

1. Direct combination or synthesis occurs when two or more elements combine to form a molecule. This is always accompanied by the use of energy.
2. Decomposition occurs when one or more elements are removed from a substance. The energy that held the atoms together is released. Decomposition can be partial or complete.
3. Substitution takes place when one or more elements or groups of elements replace one another in a compound.
4. Double decomposition occurs when two substances react to form two new materials.

Fortunately, few chemical reactions take place at ordinary temperatures without some helping means. Otherwise, nothing would be stable. We wouldn't have any food, wood, flowers, fruits, and seeds. It is bad enough when ice cream melts at regular room temperatures. It would be appalling if it were completely to fall apart into its original elements or change into something else before we could taste it.

Anything that helps speed up movements of the electrons, or that exposes as many of them as possible to assisting agents, aids in starting and quickening chemical reactions. Many things are changed by light. That is why certain medicines are placed in colored bottles, why wine is kept in a dark cellar. Some substances, especially gases, are affected by pressures. A small molecule of a substance will react much more quickly than a large one. When we cut or crush something into very small pieces we expose that much more surface to chemical reaction. It is much easier to light a piece of paper than a log of wood or a big hunk of coal. Many chemical reactions can take place only in liquids. When certain substances are placed in various fluids, the molecules and atoms detach themselves and spread out, exposing a vast surface of electrons to chemical reactions. One of the very best means of speeding up chemical reactions is applying heat, which loosens and liberates the electrons. The higher the temperature of a substance is raised, the more electrons are freed. The rate of a chemical reaction, up to a certain point, is doubled for each fifty-degree rise in temperature.

Most substances that make up the bodies of living organisms, as well as the foods that they use, can be chemically changed only by very special agents called enzymes. These are manufactured by living organisms for their own use. Digestion and many other chemical processes in living organisms are started and speeded up by the use of special enzymes. There are specific ones for every job. In the presence of proper enzymes, changes may go on in living cells at rates that would otherwise be possible only at killing temperatures. We can extract certain enzymes from living tissue, and when stored under proper conditions they can retain their power for years. A very small amount of an enzyme will affect an enormous quantity of matter. The special enzyme that changes starches to sugars is able to transform a thousand times its weight without disintegrating or weakening at all.

Colloids are gelatinous compounds, characterized by a tremendous number of atoms in their structure, which have both solid and liquid properties. Their structure facilitates many chemical changes. Colloids can absorb an enormous amount of water, and when they do, they expand with terrific pressure. The great force that seeds exert when they start to germinate is due to their colloidal nature. Colloids are greatly affected by water and are called sols when they absorb large quantities. When water is removed from them, they coagulate and are termed gels. As they usually carry an electric charge, ions can enter them freely. Enzymes are colloids. As we shall see, there are many kinds of colloidal systems.

Fig. 8. As air moves wind is formed.

5. A BREATH OF AIR

THERE is no special element, life. The elements that constitute living matter come from the air, water, and earth. By far the largest percentage of the substances making up a plant come from the atmosphere. In fact, 95 per cent of the weight of most plants comes from the air.

The atmosphere is composed of a mixture of gases into which enter water vapor, smoke, dust, tiny living and dead organisms, and common salt from the sea. All these play important roles in the life of plants. The permanent portion of the atmosphere consists of gases. In every 10,000 parts of air, there are 7,800 of nitrogen, 2,100 of oxygen, 94 of the inert gas argon, 3 of carbon dioxide, and 1 of hydrogen. The remaining two parts are made up of traces of other inert gases, such as helium and neon, and chemical gases in the form of smoke from factories.

Nitrogen

Nitrogen is one of the main raw materials used by plants for the manufacture of food. It is almost inactive in its pure form and only slightly soluble in water. Therefore, although 78 per cent of the atmosphere is made up of this element, plants are generally unable to use it directly from the air. During electrical storms some nitrogen is combined with oxygen and water vapor and brought down to earth by rain

and snow in soluble form. This amount, however, will not meet all the needs of most plants. Certain plants belonging to the pea family have attached to their roots small lumps called nodules. These nodules contain special bacteria that are able to take in nitrogen directly from the air and fix it in the soil. But the principal source for most plants is special bacteria in the soil which transform this vital element into a soluble form in sufficient quantities.

Nitrogen is essential for life and growth. The rate of growth of plants is dependent more upon this element than upon any other single factor. In combination with other substances, it forms the necessary proteins that are a vital part of all growing cells. No organic matter can break down or decay, no living organism can be built up, without some reaction of this important element. When it is lacking, the plant is stunted. The leaves become pale and die. On the other hand, when the plant receives too much, growth is too rapid and weakness in structure results. A certain balance between nitrogen and other essential elements is necessary for plants to grow, mature, and give fruit with highest efficiency.

Oxygen

All living things must have oxygen. It is the most abundant element, comprising half of all the substances on the earth's crust. From half to three quarters of the tissues of plants are made up of this ingredient. Almost the whole weight of water is due to oxygen. It readily combines with other substances.

When an element combines with oxygen, we say that oxidation is taking place. If this happens slowly, only a small amount of energy is released and the resulting temperature is not high. During rapid oxidation, great heat is produced, a flame is seen, and we say that combustion is occurring. Rusting is slow and burning is rapid oxidation.

Certain bacteria, yeasts, and enzymes oxidize compounds. Sometimes they do this very slowly without finishing the process. Such slow unfinished oxidation is called fermentation. By controlling this action we produce alcohol, wine, vinegar, beer, and cheese.

The oxidation of foods is called respiration. This is the process whereby oxygen, with the help of special enzymes, combines with the carbon in foods. This combination of oxygen and carbon is then released into the air as carbon dioxide gas. Respiration is the means by which foods are broken down in plants as well as in humans and animals. In the process the energy essential to life processes is released. The energy liberated is expressed in units of heat called calories. During the growth period, about 1 per cent of the dry weight of a plant is used daily for respiration.

The respiration rate is greatest when growth is rapid. When the supply of oxygen is reduced, respiration will be slowed down. If the supply

is cut off, respiration will cease and the organism will die. Most green plants take their oxygen directly from the atmosphere. Some plants and plant parts are able to utilize the oxygen stored in their foods without using any from the air.

Hydrogen

Hydrogen, having only one proton and one electron, is the lightest known element. One per cent of the earth's crust is made up of this element. As it forms water when combined with oxygen, it is present in all living cells. Petroleums, various kinds of oils, and aromatic substances are made when it combines with carbon.

Hydrogen has a special importance as a positive ion—in other words, as a simple proton without the outer electron—in the formation of acids and bases. Acids are sour substances we find, for instance, in lemons and vinegar. The bases are alkaline products such as ammonia. The relative concentration of the hydrogen ions determines the degree of acidity or alkalinity of a substance. As a matter of convenience hydrogen-ion concentration of solutions is expressed in a scale reading from 1, which designates the highest possible acidity, through 7, which indicates neutrality, to 14, which represents maximum alkalinity. The scale is represented by the symbol pH. Most plants prefer a slightly alkaline reaction between pH 7.2 and 8. Cranberries living in bogs have adapted themselves to acid soils having a pH as low as 5, as have other plants. Alfalfa, cacti, and many desert plants can tolerate alkalinity as high as pH 9.

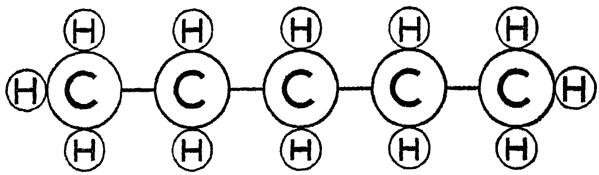
When hydrogen is removed from a compound, a process called condensation results. The compound breaks down, and during the process water is removed. The process is involved when sugars are changed to starches. When starches are changed back to sugars, hydrogen is taken in and combines with oxygen to add water to the substance. This process is called hydrogenation.

Carbon

Carbon is the cornerstone of the organic, or living, world. Half of the dry weight of plants consists of this vital element. No other is so well adapted to the special needs of living matter because chemical reactions in its presence take place at a slow and even rate.

The carbon atom can combine in so many forms that the number and variety of its compounds make up an entirely special study called organic chemistry. Over 250,000 carbon compounds are known, and hundreds of new ones are constantly being discovered in nature and made in laboratories. It can combine with itself so readily, atom to atom, that long stable chains or rings are formed in unending number. It is the

main element of living matter around which other atoms attach and arrange themselves (Figs. 9, 15).



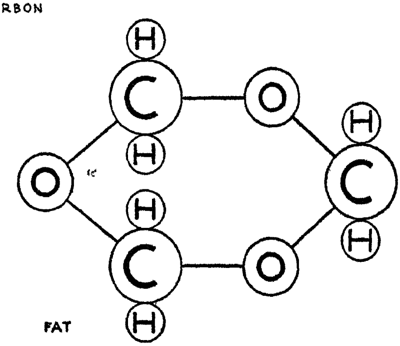


Fig. 9. (Above) How 5 carbon and 12 hydrogen atoms may arrange themselves in a chain to form a hydrocarbon molecule (Below) A ring-shaped fat molecule formed from 3 carbon, 3 oxygen, and 6 hydrogen atoms

It enters the plant as carbon dioxide gas. Millions of years ago, there was much more carbon dioxide in the air. For this and other reasons, vegetation was much richer than it is today. It was then that the present oil and coal deposits had their origin as trees and other living organisms.

All the coal and oil still in the ground and unused; all the wood, paper, clothing, and thousands of other items made from organic substances; all the living plants and animals, as well as all the carbonates that are in the oceans and in the soil, hold tremendous quantities of carbon locked up in them. When any organic matter is decayed, fermented, and burned during the respiration of plants and animals, and when volcanoes erupt, carbon is released back into the air in the form of carbon dioxide.

Up to a certain point, the more carbon dioxide gas present in the air near a plant, the better its growth will be. Out in the open field we cannot easily increase the amount without a great outlay of money. Under controlled conditions in greenhouses and in special water-culture installations, experiments with increased amounts of carbon dioxide are showing satisfactory results.

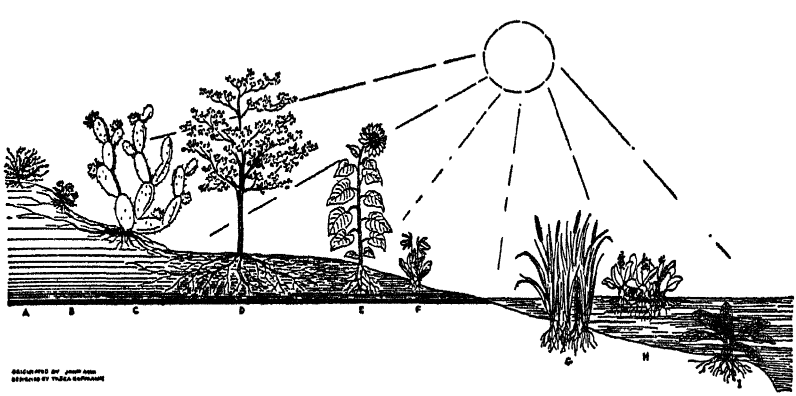


Fig. 10. Plants in relation to their water environments: (a, b, c, Xerophytes), (a) golden fleece, (b) sand verbena, (c) cactus (d, e, f, Mesophytes), (d) oak, (e) sunflower, (f) crocus (g, h, i, Hydrophytes), (g) cattail, (h) water fern, (i) lattice leaf

6. WATER—THE LIFE-GIVING FLUID

LIFE as it is known on this planet would be impossible without water. Living cells are, to a great degree, water organisms with certain other substances dispersed in the fluid. From 70 to 90 per cent of the active cells in plants, and at least 10 per cent of "dry" seeds, spores, buds, and other dormant plant parts, contain water. In other words, most plants have more water than all other substances combined.

All cells and tissues of living organisms must be saturated in this liquid in order to carry on their normal life activities. All materials that enter the plant must do so in water solution. Water is the great solvent of nature, through which plants take in food and distribute it to their separate cells.

Each kind of plant flourishes only where it finds suitable water relations. In an altogether dry location, no plant can exist except certain bacteria and other low forms of plant life, and even they can survive only during their dormant period.

Vegetation is divided into three main groups, depending on water environments: water plants, or hydrophytes; ordinary land plants, or mesophytes; and desert plants, or xerophytes (Fig. 10). Water plants such as latticeleaf, chara, and red algae live entirely submerged in water; duckweeds, water ferns, and the tiny microscopic plants that make up the plankton of the seas float on the water; cattails, rice, and water lilies are rooted under water.

Ordinary land plants need a continuous supply of water from the soil and an atmosphere that contains a certain percentage of humidity. Tropical rain forests develop in warm regions that receive over 60 inches of rainfall yearly. Various types of subtropical and Temperate Zone woods and forests exist where the annual precipitation averages between 35 and 60 inches. Chaparral, brush, maquis, prairie grasses, and other field, bush, and herb plants grow where the annual rainfall is between 20 and 35 inches.

Plants that are able to live in regions that receive less than 20 inches of rainfall annually make up the desert vegetation of the world. Many plants growing in arid regions have no special adaptations for conserving water but instead have very extensive shallow root systems. All the water that penetrates the soil and is caught and held by the soil particles, organic materials, and other substances in the ground is stabilized and remains in that place until it is removed by some outside agent. An area may receive five inches of rainfall yearly, which may wet the soil to a depth of a few feet only. The roots of certain desert plants are shallow and so extensive that they are able to penetrate and tap several hundred square feet of that wetted area. Such a root system can supply a plant with as much water as the deep narrow root system of an ordinary land plant. Many desert plants such as certain cacti are able to conserve water by having very few almost closed pores, or stomata, in their green stems, which assume the functions of the missing leaves.

Many plants that live in areas where there are short rainy and long dry spells have developed ingenious systems for storing large quantities of fresh water in their tissues. Some plants can accumulate enough to last several years. Voyagers have saved their lives by tapping the water stored in bottle trees, eucalyptus roots, traveler's-tree, and certain cacti. We enjoy many fruits and vegetables such as watermelon, tomatoes, and citrus fruits because they are storehouses for water. When there is a shortage, young growing portions of the plant will draw on this stored supply; and we suffer from loss of crop. The failure of many crops is due more to water shortage than any other single factor. Woody plants and perennial herbs are able to arrest all growth and become dormant during periods of drought, then continue their arrested growth when rains appear again. The desert annuals grow rapidly, flower, and produce seeds during a short growing season. Their thick-coated, resistant seeds lie dormant on the ground for many months or years until sufficient rains fall to enable them to germinate, grow, and produce seeds in turn.

Rapid growth can take place only in the presence of and with the use of large quantities of water. When the amount diminishes, growth slows down. For some perennial plants this is beneficial. In the fall, when the temperature goes down, the intake of water is lessened. Flower buds

are formed, which next spring will open and produce flowers. These will later give rise to fruit. While seeds, spores, buds, and wood are being matured, water is removed. Nature preserves bacteria, lower forms of plant life, and many other living organisms by lowering the water content. This brings the organisms to a dormant state which continues until conditions suitable for growth prevail.

Drying, which is taking water away from a substance, helps to conserve food in storage. This fact has been applied by food industries. Milk is evaporated. Tea leaves and coffee beans are dried. Grapes are processed and dried to form raisins. We use dried plums as prunes. Many other plants and plant parts are preserved in this way.

Most of the water of ordinary land plants enters through the roots. The quantity absorbed depends upon the amount of water that is free between the soil particles in the earth, the extent of the root system, and the temperature of the soil. But all exposed portions of plants absorb some water directly from the atmosphere unless they are covered with wax, resins, cork, or dead cells. Spanish moss, many orchids, and other plants that grow as attachments on trees, but do not feed on them, have special adaptations of their leaves, stems, and roots which enable them to absorb all their water directly from the atmosphere.

As water enters the plant, it brings along certain mineral substances. Some of these would enter anyway through the feeding roots, but not enough for the requirements of the plant. As the water goes up, a certain amount passes from cell to cell and from tissue to tissue. It is taken up and used by the cells in the formation of the plant structure and its organs and remains stationary. In coming to the leaves, a small amount is chemically combined with carbon. This action produces the first food in the form of sugar. A large quantity is used to transport material from one part of a plant to another. Some of the movements of leaves and flowers and the gradual or sudden opening of fruits to distribute seeds are due to the removal of water from special supporting cells.

We do not know exactly how water moves up to the highest branches and twigs of huge trees. The actions of living cells, the pulling forces of evaporating water, capillary action, and other mechanisms in the leaves, stems, and roots are believed to play a part in the process.

The total water content of a plant at a given moment is very small in comparison with the enormous quantities that pass through it. Only a very small percentage of all that enters is used up. In order to manufacture 1 pound of dry food matter, from 200 to 1000 pounds of water must pass through the plant. One date palm can remove about 500 quarts of water in a day and over 35,000 gallons in a year. An acre of corn will remove almost 500,000 gallons of water from the soil in one season. Some plants are very efficient, others wasteful, with the water they take in. At different periods of growth, the plant needs varying

amounts. When young and growing rapidly, it uses a great deal; when old and growing slowly, much less.

When matter is stored for future use, or combined to form structures and organisms, water is removed and the substances are so chemically arranged that they become insoluble. On the other hand, when matter is taken out of storage for use, it is made solvent. The changing of sugars to starches for storage and back again to sugars as solvents is an activity that goes on ceaselessly in plants.

The process of the loss of water by plants is called transpiration. It is unavoidable in land plants. The rate depends mostly on the percentage of humidity in the atmosphere, on light and temperature and air movements. It is a physical process over which the plant has very little influence unless it has special mechanical structures or features to minimize the loss. Most water is lost through the leaves. Some plants conserve water by having no leaves, short spurs instead of leaves, or waxy coverings, like the pineapple; others have a thick surface layer over the leaves. The leaves of many plants roll up, and a few have outer cork tissues.

Transpiration helps the movement of solutions into upper leaves where these are used. The plant is cooled by this process as a large percentage of the energy of the sun falling on the leaf is used to change the water into vapor.

Some plants liberate large amounts of water as drops. This process, called guttation, usually takes place in late spring when warm days alternate with cold nights. It is different from dew, which is a result of the condensation of water vapor already in the air.

Certain cells in many plants have special structures enabling them to exude water as drops. Some of these act as glands that secrete watery solutions of sugars and aromatics. Nectars, calcium salts, resins, gums, enzymes, sweet-smelling oils, mints, spices, vile odors, and poisons of all kinds are manufactured and released by plants.

Instead of completely benefiting plants, transpiration is often detrimental. When there is not enough water in the soil, or when there is a greater loss than intake, harm will result. Leaves fold and the plant droops. When water is taken in again, the plant will regain rigidity and be able to function once more. When wilting goes on too long, the plant is permanently injured and dies. The greatest cause of crop failures is lack of sufficient moisture or too high a rate of transpiration.

There must be a balance between intake and transpiration of water for a plant to thrive. When there is too much water, fruits and other plant parts will burst. Growth will be weak and the plant susceptible to insect and disease attack. When there is not enough, the plant will first take water from fruits, seeds, and other parts, and when the stored water is used up, will wilt and die.

Practically every activity of plants is closely interlocked with their water relationship. Every cell, tissue, and organ is so dependent on this fluid that whenever any activity in the plant imperils the proper water balance, nature has brought about a compromise in the structure and arrangement of the plant.

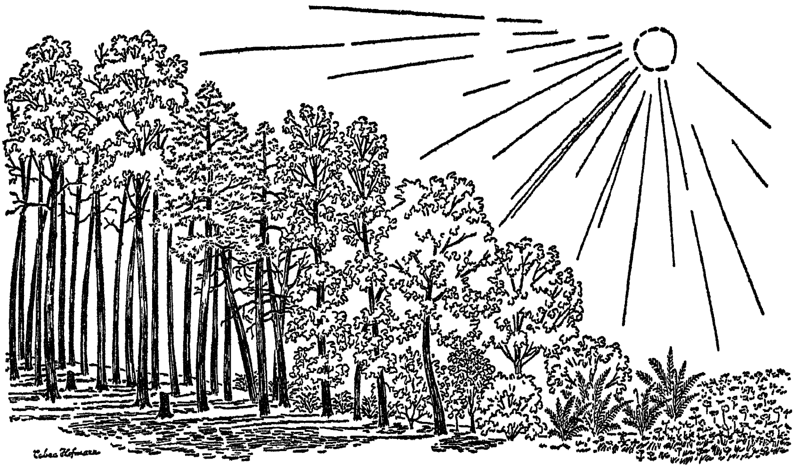


Fig. 11. In their struggle for existence plants have evolved in many ways, adapting themselves to differences in light intensities.

7. AND THEN THERE WAS LIGHT

LIFE on this earth is possible only because green plants are able to capture the energy coming to us from the sun in the form of light. They are the only organisms that are able to store this energy in a manner that all living organisms can use. Both water and light supply plants with materials that are necessary to build up their structures. Light, therefore, is as important as water in determining the make-up of plants.

Inside every atom is stored the energy necessary to keep the electrons forever racing around. We have learned that at absolute zero temperature the electrons and atoms are at a standstill. When they are warmed, they are activated. When they are hot enough, they start jumping about violently. Electrons from the outer shells give us the radiant invisible heat that comes to us from a heated object or that we feel when we stand near a fire. On the surface of the sun there is great heat, and electrons from inner shells are released. These give us our visible light rays, which are used by plants. Within the sun, the temperatures rise steadily and the rays sent out are increasingly powerful. In the very center of the sun, the heat is so tremendous that atoms are disintegrated into very tiny particles.

As far as we know definitely, only the radiant energy that comes in

the form of light is used by plants. A certain amount is changed to heat on the surface of the leaves. Some of this heat is used during transpiration to convert the water leaving the plant and release it into the air as water vapor. Another small part of the light is reflected by the surface of the plant. The darker and smoother the surface, the more light absorbed. A light surface reflects the waves. A rough, hairy surface scatters them. Of the light that enters the plant, a part is used as energy in combining the carbon and water to form the first molecules of carbohydrates in the form of sugars. The rest of the energy either is stored, locked up in the form of food, or becomes a part of the plant structure. Both plants and animals use the stored energy for their life activities. Dead plant and animal tissues and their products are broken down by living organisms, which use the released energy in their life processes. When organic products are burned as fuel, compounds are broken down. The original elements are released, and energy is given off in the forms of light and heat.

The effects of light on plants are so closely related to other factors, especially temperature and water, that it is very difficult to separate them. Under most conditions the quantity of light received is sufficient for the normal requirements of practically all green plants. When there is a great deal of light, the temperature goes up; and the plant is affected by the higher temperature more than by the intensity of light. A plant that receives enough water and other necessary nutrients absorbs and uses more radiant energy than one growing in an unfavorable environment. As light is so vital to plants, there are many ways in which they have adapted themselves to get the most benefit under varying conditions. They therefore respond to light in many different ways (Fig. 11).

The primary response to light is the production of special green pigments, called chlorophyll, which are present in every green cell. It is these bodies that have the power to combine carbon and water by the use of radiant energy to form the first sugars. This most important function of all chlorophyll bodies is called synthesis. There is a remarkable resemblance between the chlorophyll pigments of plants and the red corpuscles of human and animal blood. Both are made up of the carbon, hydrogen, oxygen, and nitrogen elements. But, whereas the green plant pigments contain magnesium, the red pigments have iron.

The green chlorophyll bodies of plants can be activated only in light, and they arrange themselves in different ways in order to receive the best illumination (Fig. 12). At the same time, the cells making up the leaf arrange themselves so that they should not lose too much water. The arrangement of the parts of a plant represents a compromise between these two vital factors. Different plants and the leaves of individual plants have adjusted themselves to various intensities of light so

that, for example, a shade plant requires less light than one that must be fully exposed.

As we shall see in a future chapter, the opening and closing of the small guard cells found in the leaves and other organs are greatly affected by light. These cells regulate the intake and release of certain gases and water. Therefore light, both directly and indirectly, controls many activities of plants.

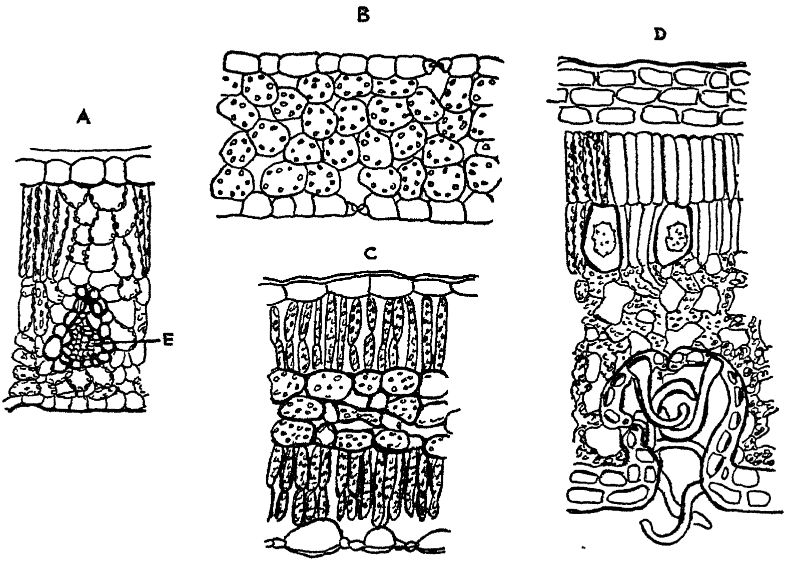


Fig. 12. Cross sections of: (a) A typical horizontal leaf in bright light, (b) typical horizontal leaf in shade, (c) erect leaf in strong illumination, (d) leaf showing depressed stomata and calcium crystals, (e) vein

The exact composition of light coming in contact with plants is highly dependent on atmospheric conditions, especially the amount of moisture and dust in the air. The permanent gases and water absorb part of the light, scatter and change it. Dust particles, clouds, fogs, mists, and smoke reflect light in various degrees. In high elevations the air is not so dense. There is less dust, moisture, and haze. There is less absorption, and therefore the light is more intense. Alpine plants are greatly affected by this very strong light. They have short stems, firm leaves, and very wrinkled surfaces.

The quality of light on clear days is very much the same everywhere. Even in dense forests the dim light that falls to the ground is white. It is either reflected or filters down between the branches and leaves. It does not pass through the leaves. The thickness of just one leaf is often

enough to screen the light so completely that the one below cannot manufacture food.

Most plants, when growing in the open, do not move in response to light. However, the leaves of cotton and the flowers of young sunflower plants do turn with the sun. Some are so sensitive, especially wild lettuce, that they place their leaves in a north-south direction and are called compass plants. Those growing at the edge of forests, in dwellings, near buildings, or in any locality where the light comes from only one direction have a tendency to bend toward the light.

The intensity of light varies throughout the day, season, and year. The daily maximum occurs when the sun is as near overhead as it can be—in other words, at local noontime. Just at sunrise and at sunset, when the sun is very low, its light passes through such thick layers of air, dust, and water vapor that it contains little energy that can be used by plants. Although all green plants require light, certain low forms of plants live in dark cellars, in the ground, and at great depths in the seas. Many of these are killed by exposure to light.

Reduction in light intensity tends to increase the length of stems and branches, and to enlarge leaves. When there is too little light, chlorophyll is lost and the exposed portions will become pale yellow or white. Celery, cauliflower, endives, and other plants are bleached by being covered against light. In many plants, the largest leaves and the fullest development occur in partial shade, which increases succulence and delicacy of structure. The best qualities of asparagus, celery, lettuce, rhubarb, tea, and tobacco for cigars are grown in the shade. Intense light favors the development of flowers, fruits, and seeds. In open fields there are many flowers. In dense forests very few are found near the ground. Artichokes, tobacco, coffee, and the huge redwoods grow best in foggy places where the light is not strong. It is because some plants prefer light and others tolerate shade that layering in forests takes place. The uppermost leaves that must have full sunlight are exposed to the highest light intensities. The other growths arrange themselves in height in proportion to the amount of light they can tolerate. The ferns and other forms that need most shade grow on the ground. Many mosses will not grow in full light, but only on the northern side of trees. This fact helps people find their direction in forests.

Effect of Length of Day

Owing to the shape of the earth and the tipping of its axis, the duration of the light—in other words, the length of day—varies. In the tropics the days are close to twelve hours long all through the year. The farther away one goes from the equator, the longer the day in summer and the shorter in winter. Plants in temperate lands experience a short day in early spring, a long day in summer and early fall, and a short

day again in late fall and winter. The rapid midsummer growth in those lands is due to the increased amount of sun they receive.

Certain plants require relatively long days for successful flowering and fruiting, some are indifferent, others need a short day. Many fruit trees, bulbs, and violets bloom only in the spring, when the days are getting longer. Long-day plants, such as clover, the cereals, grasses, poppy, and rhododendron, flower in late spring and early summer. Tobacco and soy beans bloom only in late summer, while zinnias, chrysanthemums, and asters bloom in the fall. In cool regions many short-day plants can blossom only in the fall, as they need the necessary time to accumulate sufficient quantities of food. Oranges ripen around San Francisco earlier than around Los Angeles because they experience a longer day in the former place. There is a wealth of vegetation in Alaska due to the long summer days in that northern locality. Many plants such as the potato produce their thickened underground stems, which we use as food, only when the short days in the fall start. Plants that require long days will suffer when moved to the tropics; likewise those that can flourish only with a short duration of light will not grow well when moved north. There is a correct time for planting each kind of plant in relationship to its light requirements.

Natural sunlight may be supplemented with electrical illumination to hasten the development of plants. This technique is widely used in greenhouses by flower and vegetable growers, who can thus be sure of producing their flowers and fruits for special occasions. No matter what the weather may be, Easter lilies for Easter and carnations for Mother's Day are always plentiful.

Color

White light, as it comes from the sun, is composed of several bands of visible rays. The longest waves we can see are red, and in decreasing wave lengths we can distinguish orange, yellow, green, blue, indigo, and purple. When all the light rays are absorbed, an object appears to be black.

The various chemical compounds in plants and some surface cell walls and other plant coverings absorb certain rays and reflect others. We receive our color impressions from the rays that are reflected back to us. For the sake of convenience we call all substances that give us color sensations pigments. We say these materials are of such-and-such a color when that sensation is reflected to our eyes. A substance that reflects red is a red pigment. We also receive various kinds of color sensations when the reflected rays of two or more pigments or surfaces arrive at the same time and are blended together. When red and yellow are blended together we see orange.

Over two thousand different kinds of pigments are secreted by plants.

About 130 of these are of considerable economic importance and are used for coloring paints, varnishes, leather, ink, paper, wood, medicines, foodstuffs, and textiles.

Green is the distinctive color of the plant kingdom. This green coloring is due to the chlorophyll bodies, which reflect green back to us. In the leaves of plants there are other pigments that are hidden from view during the growing period. When the chlorophyll bodies disintegrate in the fall, the others are unmasked and we see the beautiful autumn hues. Some leaves and stems of certain plants do not contain many chlorophyll bodies, but do possess a large quantity of other pigments. There are leaves, stems, roots, flowers, fruits, and seeds of all imaginable colors.

Substances called carotinoids, because one of them was first found in carrots, give us the yellow and orange colors, and are very rich in vitamins. Another group of pigments reflects the reds, blues, and violets. All forms of plant life manufacture their special pigments, which give them their distinctive colors.

The formation of these pigments depends upon many factors. Some pigments, like those in many flowers and fruits, are made only at certain stages in growth; others are always present. Many are formed in light, while others, like the red color in beet roots, can be made only in darkness. Some are manufactured when temperatures begin to go down, others in the spring when it starts to be warm. The red pigments of many fruits must have light. The fruit near the ends of the branches on many trees is much more highly colored than that found inside the crowns. Some, like the chlorophyll, certain enzymes, and those that attract insects, perform essential functions. The role of many is not clearly understood. The pigments react in many ways to different conditions. Red is usually associated with an acid quality, blue with alkalinity.

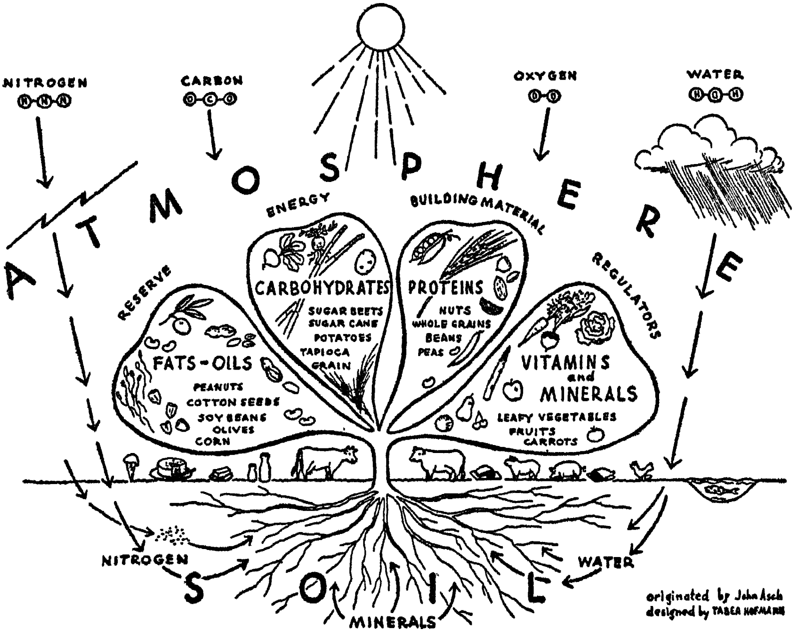


Fig. 13. How the elements enter plants, and the kinds of foods that are formed

8. WHAT IS FOOD?

LIVING processes can take place only by the use or release of energy. The source of all this energy is food. Foods are present in a great variety of substances. But in whatever shape or form they are found, their primary importance is due to the energy they contain and the many processes they control. In general, animals can use only the energy stored in foods. It is the green plant that accumulates it and changes it into a form that all other living things can take in, transform, and use for their own activities.

Plants are unique because they can manufacture the food they need from a few simple substances. The amounts and types of materials entering a plant are not affected by the quantity of water taken in, although substances and water are absorbed together.

The interchange between the different elements in a substance, their combinations and uses, are so complicated that we do not understand many of the processes taking place. We sometimes can tell the start of

a reaction and its finish, but the intervening changes are hidden from view. Living cells are not stable like stone or steel; they are constantly being built up and broken down, taking in and expelling matter. This continuous change makes the entire subject very obscure. It is therefore difficult to tell the specific role of each element. When one is missing, when there is too much of any one, or if elements are combined in such a form that they are unavailable or toxic, the entire structure and activity of the organism are changed.

Carbohydrates

Most green plants receive their carbon and oxygen directly from the air. Other elements, including their water, which is made up of oxygen and hydrogen, are absorbed through the roots. The first simple food is a carbohydrate (Figs. 6, 14) in the form of a sugar resulting from a combination of carbon and water.

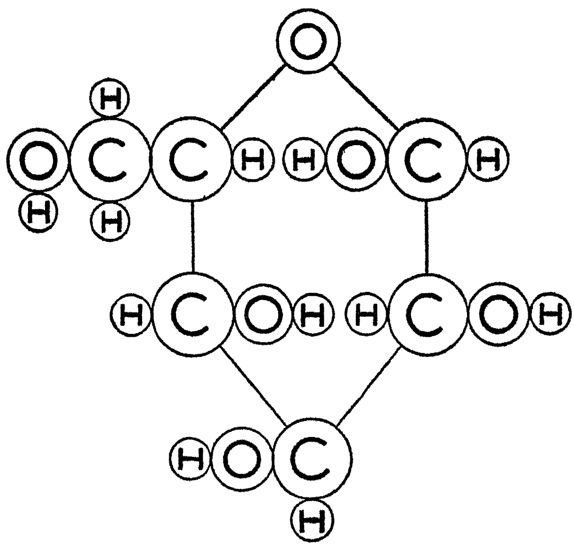


Fig. 14. 6 carbon, 6 oxygen, and 12 hydrogen atoms arranged in a ring to form a carbohydrate molecule

The numerous carbohydrates are the most abundant substances in plants and they serve many useful functions. They form the supporting tissues of plants and are important storehouses of energy.

Most of the carbohydrates are accumulated in the form of starch. Our main food products come from those stored starches in potatoes and such grains as wheat, rice, and corn. The coal and petroleum we use in such tremendous quantities originated as carbohydrates.

Cellulose forms a large part of the cell-wall material, especially in wood. Cotton is almost pure cellulose. We use this kind of carbohydrate in making paper, plastics, clothing, and many other products.

Fats and Oils

During certain complicated chemical processes, some oxygen atoms are removed from certain carbohydrates, forming fats and oils—or lipides, as they are sometimes called (Fig. 9). When they are solid we call them fats. In liquid form they are known as oils. When these processes are reversed and oxygen is added, the lipides are changed back to sugars, starches, and other forms of carbohydrates. As lipides are soluble in water and contain a great quantity of energy in a compact form, plants change many carbohydrates to lipides for storage. A pound of fat contains more than twice as much energy as a pound of sugar. We use the oils in almond, cacao, castor bean, coconut, corn, cotton, flax, olive, peanut, soya, sunflower, tung, and scores of other fruits and seeds for a wide variety of purposes—as foods, as cooking fats, in the manufacture of soaps, for paints, as cosmetics and lubricants.

Many complicated forms of fats also contain other elements. These give the special taste to mustard, garlic, onions, many spices, fragrant herbs, and oils used in the perfume industry. Some are found in the forms of gums and resins. Balsams, turpentines, myrrh, vanilla, and cinnamon are all forms of special fatty substances. Leaves, stems, roots, flowers, fruits, and seeds are covered with waxes that preserve water and prevent mechanical injury and the entrance of harmful diseases and insects.

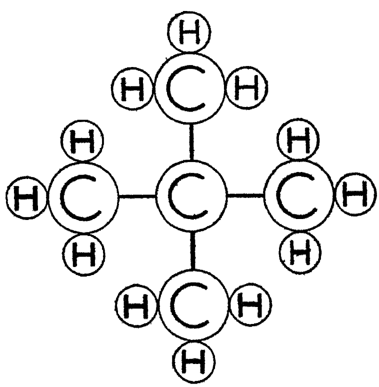


Fig. 15. A hydrocarbon molecule made up of 5 carbon and 12 hydrogen atoms

When all the oxygen atoms are removed from a carbohydrate, a hydrocarbon is formed (Figs. 9, 15). Our petroleums, many resins, essential oils used in cosmetics, a vast range of dyes, and many of the aromatic substances in perfumes are made from the different combinations of the carbon and hydrogen atoms.

Proteins

When nitrogen is added to the carbohydrate molecule, substances called amino acids are formed (Fig. 16). Over thirty different kinds of these have so far been identified and studied. Their products form in-

numerable combinations, only a few of which are known to date. These amino acids manufacture proteins, which play a role vital in all forms of living matter. The word itself is from a Greek word meaning primary. Many proteins contain other elements, such as sulphur, phosphorus,

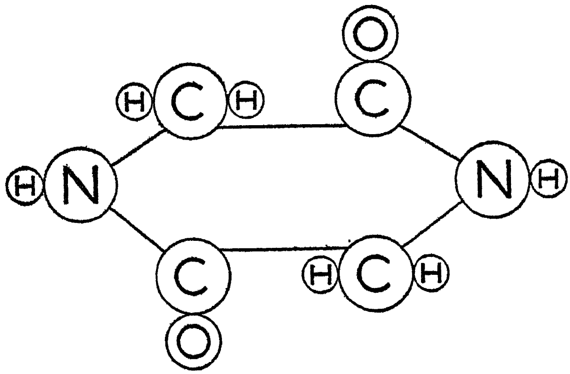


Fig. 16. 4 carbon, 2 nitrogen, 2 oxygen, and 6 hydrogen atoms arranged in a ring to form an amino-acid molecule

and iron. It is difficult to distinguish the many types, as they are very complicated. Some have over half a million atoms in their structure. Many are insoluble in water and they can be moved about only when changed back into the form of amino acids. All genes, enzymes, many growth stimulants, vitamins, and pigments are types of proteins (Fig. 17).

Every kind of plant has its particular proteins. Someday when they are better understood, the classification of plants will be largely based upon the proteins found in them. The proteins of one species are often not related and in many cases are not even tolerated by another. The specialty of manufacturing specific organic materials in plants and its marvelously exact repetition, cell after cell, generation after generation, is one of the great wonders of nature.

Plants and plant parts that have high fat and oil content usually contain large quantities of proteins, especially the seeds of the pea family, such as beans, peas, and lentils. As all growing tissues are rich in proteins, the layer of cells near the outer skin of fruits and vegetables should be saved and used, not cut off and wasted.

Other Essential Substances

Carbohydrates, fats, and proteins, the three primary and essential types of foods used by all living organisms, are made up of only a very few of the elements found in plants. The other substances are used in

manifold ways. The relative amount of an element within the plant, even its presence, by no means indicates the necessity or importance of that element, which can be determined only when the plant suffers if it is missing. During the start of growth many substances are absorbed, later fewer, and when the plant is nearing maturity some are returned to the soil. In certain cases, the plant may suffer from lack of an element that is present because it is not in a soluble form. Scientists are constantly finding more elements that are needed by plants. The role of some is distinct. But the function of others is not well understood because they are probably used as agents in many chemical and biological processes.

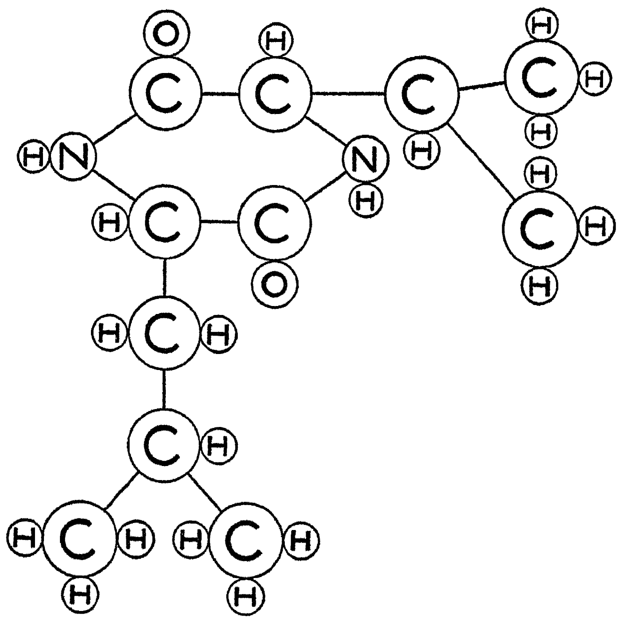


Fig. 17. Part of a synthetic protein molecule made up of 2 nitrogen, 2 oxygen, 11 carbon, and 20 hydrogen atoms

In addition to oxygen, hydrogen, carbon, and nitrogen, there are other elements needed in large amounts by plants.

Sulphur, the "brimstone" of the Bible, is an important part of many proteins and is vital for their manufacture. It gives the special characteristic odor and zest to many plant products such as mustard, garlic, and spinach. It can be accumulated in one organ, used, and when not needed any more moved to another place. Sulphur is an essential part of living organisms, and green cells cannot be formed when it is absent.

When not enough is present, the leaves will be yellow and spotted and the roots white and small.

Phosphorus is found in every living cell and is accumulated in large quantities in fruits and seeds. It readily moves from one organ to another. When the young, fast-growing parts have not a sufficient amount, they will take it away from older tissues. Phosphorus is present in all seeds, many proteins, growing cells, enzymes, and certain pigments. It acts as an important regulator of many processes.

Potassium, or potash, as it is commonly called, is used in the manufacture of many organic acids. Crops containing large amounts of sugars, acids, and starches use a great deal. It cannot be replaced by any other substance. Internal redistribution of this element occurs all the time, as newly forming and growing tissues need a great deal of it. Potassium enters into many enzymes and pigments and also acts as a regulator of chemical processes. When there is a deficiency, the entire plant suffers.

Calcium is important because it neutralizes acids. It acts as a stabilizer and aids in the formation of many products. It assists in the movements of various substances within the plant. Calcium reduces the toxic effects of poisonous compounds that develop during many processes. Also, it is necessary for building cell walls and other tissues. It remains where it is deposited within the plant and does not move from place to place like some of the other elements. A large percentage is in the leaves and stems, where it helps to keep them rigid.

Magnesium is the only mineral element found in the chlorophyll bodies. When not enough is present, the leaves of plants are spotted with many colors. It is constantly being moved within the plant from older to younger parts. Magnesium is important for the manufacture of fats, and for this reason all oily seeds have large amounts. Sometimes it acts as a carrier of phosphorus within the plant.

Iron is indispensable for the formation of chlorophyll, although it is not present in chlorophyll itself. It is a carrier of oxygen in the plant as well as in the blood of animals and humans, and it helps many chemical reactions. It is one of the most fixed of all elements, not moving at all once it reaches its place of work. It is absolutely necessary for all green plants.

Silicon is always found in plants, but its role is not clearly understood. The leaves of grass plants are very rich in this element. It seems to protect from various parasites. Boron, copper, and zinc are vital, but in very tiny amounts. Their functions are not well understood, but without at least a trace of these, plants suffer.

Sodium, chlorine, and aluminum are present in practically all plants, but whether or not these elements are needed by every plant where they are found is not known. Sodium can replace a certain amount of potash

in some plants. Iodine, barium, cobalt, strontium, molybdenum, titanium, as well as silver and gold, are found in many plants. Whether these are present because they are needed or just because they happen to be in the soil in a soluble form is unknown.

Organic By-Products

Plants manufacture other substances besides foods. Among these are various enzymes, pigments, resins, oils, latex, alkaloids, glucosides, organic acids, hormones, and vitamins.

The alkaloids are nitrogenous compounds that have powerful toxic effects on animals and humans. They are secreted in special cells or tubes and are present in many different kinds of plants. Many afford protection to plants because of their bitter taste, and are useful to man as valuable drugs. Quinine is extracted from the bark of the cinchona tree, caffeine is present in coffee beans, thein is extracted from tea leaves, morphine comes from the dried latex of poppy capsules, cocaine from the leaves of coca plants, and atropine from the stems, leaves, and roots of belladonna plants. Nicotine is present in tobacco leaves, strychnine comes from strychnos nuts, arecoline from betel nuts, and ephedrine from the roots of ephedra plants.

Certain carbohydrates that may be toxic to plants in their natural form are made harmless by being converted into various forms of glucosides, many of which are very useful to man. Indigo, which gives us a very deep blue coloring matter, is known as the "King of Dyestuffs." It comes from the leaves of indigofera plants, which are members of the pea family. Gentian, or bitterroot, comes from gentian roots, and digitalis is extracted from the leaves of the digitalis plant.

Many different kinds of organic acids are present in the cells and cell saps of all plants. These aid the work of the cells in various ways. They may appear in a free state as salts, or in combinations with certain kinds of alcohols. Some of the most common organic acids are malic from apples, citric from citrus fruits, tartaric from grapes, oxalic from rhubarb; acetic is formed in vinegar, and formic acid comes from nettle plants.

Hormones

Plants are living organisms that are made up of many tissues and organs. Each of these is in itself an intricate living system. Such a vast organism must be controlled by various factors that harmonize the innumerable activities of the countless cells. Some of the very important controlling bodies, or chemical messengers, are called hormones. They are manufactured in the buds and young growing leaves and travel throughout the plant, regulating and controlling many activities by stimulating or retarding actions. Although very little is known

about their composition and how they accomplish their work, some have been extracted and a few have been manufactured synthetically. The most thoroughly studied and best understood hormones are known as auxines, of which about fifty different kinds have so far been isolated. Some stimulate the formation, control, and elongation of cells, the growth of roots, the formation of new conductive cells and strengthening tissues, activate growing points to produce flowers, and stimulate unpollinated flowers to produce seedless fruits. Some of the natural or synthetically produced hormones are colchicine, which is used to increase the number of chromosomes; allantoin, which stimulates the formation of earlier and larger flowers; traumatic acid, which collects at a point of injury and stimulates the growth of the cells that will heal the wound; ademine, which makes healthy large leaves; biotin, which stimulates the growth of the seedling after germination; thiourea, which is used in inducing seeds to germinate and cuttings to produce roots, and also prevents cut fruit from discoloring; naphaline acetic acid, which prevents fruits and leaves from falling; and ethylene, which rouses plant tissues from dormancy and thus hastens growth.

Vitamins

Certain substances called vitamins are required in minute quantities by all living organisms to prevent various deficiencies and to keep the plant or animal body working normally. Since very little was known about them at first, they were given letters of the alphabet as names. Today a large number have been discovered, isolated, analyzed, and named. They have an important role in the science of both plant and animal nutrition.

The role of the yellow pigment, carotene, in plants is unknown. Carrots and green vegetables are especially rich in this important substance, which was first called vitamin A.

Several of the B group of water-soluble vitamins are known. B_1, or thiamin, is an important growth factor in roots. Whole wheat and the coats of many seeds are especially rich in thiamin. B_2, or riboflavin, used to be called vitamin G and seems to be a root-growth factor. Puridoxin, or B_6, nicotinic acid, and biotin are some of the other vitamins of the B complex; and their roles are similar to that of riboflavin.

Ascorbic acid, or vitamin C, is present in all citrus fruits, tomatoes, and other fruits, where it improves the keeping quality of the seeds, and is present in all actively growing plant tissues. The functions of vitamin D, vitamin E, vitamin K, and others are not as yet well understood in plants. Some vitamins, such as D, are not present in plants, but are manufactured only in animals.

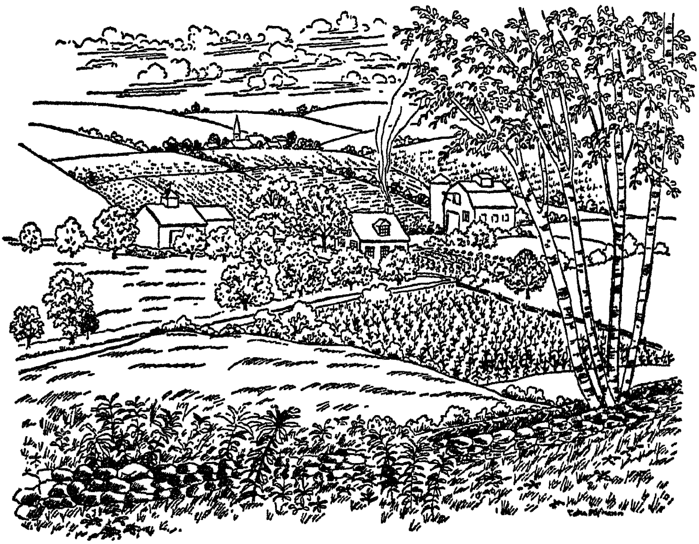


Fig. 18. A diversified farm in the corn belt of the humid regions of the temperate zone

9. MOTHER EARTH

IN the opening chapter we learned that the first living thing appeared on this earth "when the rocks were properly ground up, when the waters were cool enough, and when all the conditions for life were present." Life started in water. The migration of plants from water to land represented a great step in the evolution of the living world.

Many thousands of years ago, when man was just starting to think for himself, plants had already so well adapted themselves to the earth that a vast vegetation was growing on the land. Man gathered his food, medicinal herbs, leaves for shelter and clothing, and wood for fuel from the earth. It protected him, and he always felt safe when on the ground. The great doctrine of "Mother Earth" was so strongly developed that in his folklore, religion, and history he told how man came as dust from the earth and after death returned to it. "Ashes to ashes and dust to dust" was a universal expression.

But the earth is not a single substance, the same everywhere. When we ride by train and car, even when we stroll through the countryside

or in a city park, we notice how diversified soils are in different places. Some are dark, others light. In one place water remains a long time after rain. In another it dries out quickly. No two parcels of land are alike. Soil is so varied because it has been built up and changed by a great many separate and interlocking factors. Its study is so complicated that although as much has been written about soils as about any other subject, many things take place in them of which we know very little.

All soil factors depend upon the past history of the soil, which is determined by heredity or the original chemical composition of the rock from which it was formed, and environment or the conditions under which the original rock was broken down and changed.

Soil started to be formed when the first molten masses of the original gases comprising the earth started to solidify. These were subjected to enormous pressures under the action of which the various elements combined in many different ways with each other to form the first rocks. They were pressed together, moved about, and endured tremendous heat. Later, when the earth cooled and glaciers appeared, they underwent great cold. The rocks were moved by glaciers, water, and winds. In this way they started to break down into smaller particles. These fragments underwent further, more complicated changes after the first living things appeared. Soil is built by physical, chemical, and biological means and is continuously being changed by the work of these agents.

We say that a soil is new or unweathered when the larger pieces are at the point of being ground up and there are few other materials present. An aged or weathered soil is one that is divided into very fine fragments. It has many other substances mixed in with the original finely powdered rock material and has lost some ingredients by the action of wind, water, and gravity. Also, it has been changed by chemical reactions and living organisms. Sometimes weathering is very helpful, especially when the soil is enriched by the addition of beneficial materials or by the removal of harmful things. Weathering can be disastrous when harmful chemical, physical, or biological factors enter, or when needed materials are taken away. Lately we have been hearing the word erosion a great deal (Fig. 182). That term signifies the removal of matter from the soil. Erosion can be beneficial when bad things are removed, though it is catastrophic when needed matter is taken away.

The interactions of all the forces that produce soils leave marked individual and collective characteristics that are used as a means of classifying soils. The broadest grouping is into three orders: Zonal, Intrazonal, and Azonal. Within these orders are certain processes or conditions that are used to subdivide the orders into eight suborders, thirty-six great soil groups, over a hundred families, several hundred series, many hundreds of types, and innumerable phases.

When we look into an open ditch or a cut made for a road, we can see several distinct layers, which we call horizons (Fig. 19). These can usually be distinguished easily. The upper ones are mostly dark. They are composed of leaves, roots, and dead and decaying materials of all kinds. The next layer is lighter in color and is made up of finely ground soil particles. There are some living roots present. The third horizon is composed of the original material that is undergoing the first stages of underground weathering.

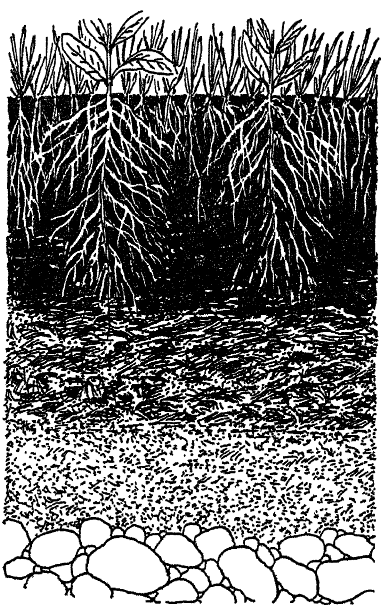


Fig. 19. Horizon of a typical fertile soil

Most ordinary soils are composed of a mixture of ground rocks of all shapes and sizes. The texture of the soil depends upon the number and proportions in which they are present. The particles range in size from stones of all dimensions to specks so small that we cannot see them, even with the aid of the most powerful microscopes. The largest of the small pieces, those that we can see easily and that feel gritty to the fingers, we call sand. Silt is barely visible to the naked eye. It looks and feels like flour. Clay particles are very small. When sand and silt prevail in the soil, we say it is sandy loam. A clay loam is composed mainly of silt and clay. There are all gradations from the pure sands we see in many deserts to the heavy clays in moist, badly aerated places.

The separate particles are usually held together in lumps of different sizes. Sometimes these are very big, especially when heavy clay becomes wet. The clods so formed are hard to break down and cause a great deal of trouble to farmers. When the lumps are small, like crumbs, the structure of the soil is excellent.

Many of the very fine clay fragments form colloidal structures. Some of these structures are essential as storehouses for the accumulation of certain necessary material that the plant can use as needed; others do not affect plant life; still others store up harmful stuffs and are injurious to plants. When colloids contain water, they act as liquids; otherwise, they behave like solids. Sometimes colloids are so numerous that they form a hard layer that may be very harmful, as the roots are

unable to pass through them. The decaying materials in the soil likewise form special colloids that also act as storehouses. When they are present in large quantities these give the gummy gelatinous nature to soils, and often the dark color.

Temperature

The earth is warmed both by the rays of the sun that strike the surface and penetrate into the ground, and from the heat present in the interior of the earth. This interior heat raises the temperature of the soil almost two degrees for every two hundred feet in depth. This is why it is so hot in mines that lie deep in the earth's crust. It is believed that some heat is also produced by the activity of radioactive elements in the rocks. When land has a cover such as rich vegetation, less heat strikes the surface. If the area is barren, the earth is hotter. The temperature in the ground varies very slightly as compared with the wide range in the air. At two or three feet depth there is hardly any daily change, only seasonal. There are smaller variations in temperature when the land is near a body of water or when there is a large amount of water in the soil. Generally speaking, soil is warmer near the tropics and colder at the poles. But this is often upset by altitude. The higher above sea level, the colder it gets. One of the main factors is slope. Land facing south is appreciably warmer than land exposed to the north. The changing elevation of the sun at different times of the year plays an important role and gives us our seasons.

Atmosphere

As there are different shapes and sizes of fragments in the soil, they do not fit together very tightly under ordinary conditions. There are,

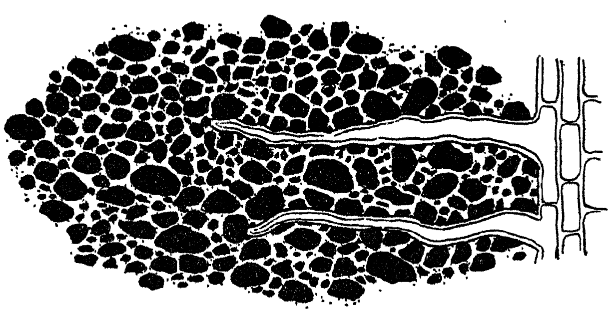


Fig. 20. Absorbing root hairs between porous soil particles

therefore, innumerable spaces between the soil particles (Fig. 20). We say that a soil is porous when it contains a great deal of air. The composition and richness of the land depend a great deal upon the

activity of living organisms in the earth. These organisms and the underground parts of plants must have a steady supply of oxygen and nitrogen, which circulate together with carbon dioxide and other gases in the soil atmosphere. For a soil to be healthy, it is essential that there be a continuous interchange between the air in the soil and the atmosphere. The quantity of air present depends upon the size and number of spaces and the amount of water in the soil. Water upon entering the ground displaces the air, as it is heavier. If the water remains, the soil air is kept out and all living things present suffer from lack of the essential gases.

WATER

One of the reasons that plants are able to live on land is the fact that soils receive, hold, and transfer water for their use (Fig. 183). Dry land is only a relative term. The spaces between the soil particles form a complicated system of connecting passages, some very large, others exceeding small. These passages continuously change in amount and size. Usually there is a combination of air and water in these spaces. When they are completely filled with water we say that a soil is saturated.

The water can come to the soil as rain, snow, and hail, through the overflow of rivers, and through man's effort in irrigation. When rain falls faster than the soil can absorb it, a large amount may run off and carry soil particles with it to a lower place. The rest moves down by the force of gravity. As it goes down, it fills up all the free space before penetrating farther. A certain quantity of water is always held tightly as a thin film around each soil particle. Another portion is locked up in various combinations of all kinds. Neither plants nor any other natural agents can remove this water. It is present even when the soil is "dry." Only the remaining amount of water is available for plants.

This "free" water can move to a limited degree by the same capillary action by which ink moves in a blotter. When the soil is very warm, some of this water is evaporated and moves as water vapor through the passages. On cooling, it condenses in another place, and so there is some movement by this means.

A considerable part of the water that enters the soil is taken up by plants. A small amount is used by them, and the rest they have absorbed is returned to the atmosphere as water vapor during transpiration. The unabsorbed residue filters down in the soil, forms underground springs, eventually accumulates, and, as streams and rivers, runs off into ponds, lakes, seas, and oceans. Unless the soil particles are held by some means, this moving water may take and transport large quantities of soil.

In nature there is no pure water. It always has slight traces of carbon

dioxide, oxygen, sometimes nitrogen and other elements. It is usually in the form of a very weak acid. In the soil, water acts as a solvent and holds varying quantities of numerous chemical compounds. This is called the water solution and is one of the most complex components of soils and the one we know least about.

Just as carbon is the keystone of the organic or living world, so silicon is the essential element in the inorganic or mineral world. It has four outer electrons, and therefore the same chemical properties as carbon.

Like that element, it enters into thousands of combinations with other substances. Both carbon and silicon play important roles in the soil by combining with a wide variety of elements.

Biological Factors

Living matter is always being born, growing, and maturing; dying, being decayed, and being broken down into the original elements, which are again taken up by other living matter and used. So the same few elements are constantly being taken up, fixed in place for a limited period of time, released, and reused.

Endless successions of generations have deposited their residues, in various stages of decay, in the soil. This organic matter plays a key role in the physical and chemical actions taking place there.

The carbohydrates, fats, proteins, and other materials are attacked by all sorts of organisms. Many of these are specialized and work on just a certain element or compound, while others are indiscriminate. Some eat smaller ones and are in turn eaten by larger organic structures. These vary in size. Some are so small that only their products can be observed, while others are huge earthworms. There may be a few per acre when there is a lack of moisture, air, and food. When new food is added and the conditions for growth are in proper proportion, they increase at tremendous speeds until there may be billions in a thimbleful of soil.

During one stage in the endless complex process of decomposition, a dark gelatinous layer of decayed matter is accumulated. This is called humus. It is always undergoing change. New materials are constantly being added to it. When these have been completely broken down, they enter into chemical combinations of all kinds. When they are changed into a soluble state, they enter the soil solution for the use of plants. In new soils humus is accumulated, while in older ones it is broken down. When the soil is not disturbed in any way, a balance is established between the amount that is being formed and that which is removed. Any change, such as cultivation, watering, planting, and removal of a crop, disturbs this balance. Humus is very beneficial, because it resists seepage and many elements are held in it in an available form. Being

porous, it also acts as an excellent storehouse for water. Soils that are rich in humus are usually superior and can be easily worked and managed.

Many low forms of plant and animal life live in the soil. Each contributes in its way to the breaking down and building up of living and dead matter. Larger animals in the form of worms and different types of burrowing creatures inhabit the soil. They work over the soil particles and are very helpful in aerating the land, in making space for water storage, and in changing materials and releasing them in a form plants can use.

As soils are a result of physical, chemical, and biological activities, they are complicated and, like living organisms, experience birth when the original rocks are broken down, growth when materials are deposited, and maturation as mineral substances, water, and organic materials are added, changed, and removed. They start to decline when they are eroded and moved, and eventually die when they are completely dried up, have lost all their organic substances, or when they are deposited at the bottoms of lakes, streams, and oceans. In time the tiny particles are welded together, changed into rocks, exposed above the surface, and start a new cycle as the new rocks are broken down again and become the foundations of new soils. Each kind of soil represents some geological stage of growth, development, or decomposition.

Nature and man use the soil, because it is an ideal medium in which many different substances can be placed, held for future use, changed, and arranged for the benefit of plants. Plant growth and production are dependent very largely upon the soil, as it gives them space in which to extend their root systems and supplies them with water, air, and many of their chemical nutrients.

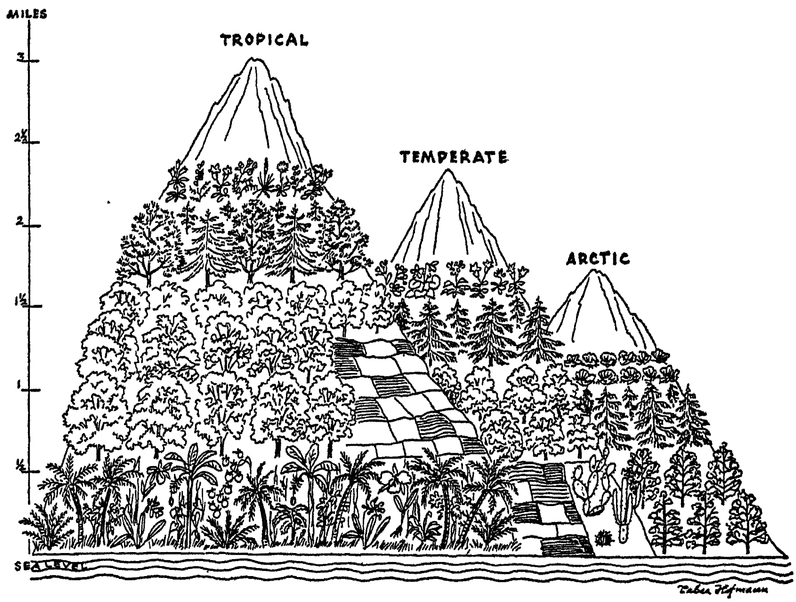


Fig. 21. Natural vegetation in relation to the three main climatic zones, as modified by altitude

10. CLIMATE

THE average atmospheric conditions that a certain locality experiences during a long period of time are expressed in one single term—climate. The weather of a particular place may vary from season to season, day to day, and even hour to hour. On the other hand, the climate of a locality does not change appreciably over a period of many years.

The differences in climate and the frequent changes in the weather are due to disturbances that take place in the atmosphere. These are caused by the variations in heat received from the sun because of the earth's spherical shape, its rotation around its axis once every twenty-four hours, its being tipped at the poles, and its yearly voyage around the sun in an oval path. Climatic changes are intensified and complicated by the irregular distribution of the land and water areas, and by differences in latitude and temperature.

Temperature influences practically every chemical and physical process that takes place in plants. It provides what we call a working

condition and energy. Most vegetation is subjected to great differences in temperature during growth. The length of the growing seasons varies greatly from place to place and year to year. The many activities of plants can take place only when the right amount of warmth is present. Some can withstand great heat, such as certain low forms of algae that live in hot springs having a temperature of almost 200 degrees Fahrenheit. At the other extreme, there are arctic plants that are not killed by temperatures as low as 90 degrees below zero. Most plants can grow only within a range that extends from about 20 to 120 degrees.

Many plants, such as cotton and lemon, can grow only in warm climes and are killed by a very small amount of frost. Pears, grapes, and cherries can thrive under a wide range of temperatures. Sugar maple and certain conifers must experience some frost every year in order to grow well. Very often the optimum temperature for plant growth is not the best for commercial crop production because too rapid growth and luxurious vegetation weakens structures.

A plant must accumulate a certain amount of food in order to grow properly to its normal size, carry on its activities, reach maturity, produce good seeds, and ripen its fruits. The most important external factors controlling the quantity of food manufactured are light and heat. When a plant has reached a particular stage in growth we can say that it has received a certain total amount of energy. Each kind of plant must receive at least a minimum amount in order to accomplish each phase in vegetation.

Many plants offset great differences in temperatures by storing up food in various organs during the growing season. When they have accumulated enough they are able to flower and fruit. Annuals, such as tomatoes, beans, and cereals, manufacture enough food during one season to be able to bloom and seed before being killed by the first frost in the fall. Biennials need an entire season just to manufacture and store adequate quantities. They must wait until the following year to send up a flowering stalk. Beets, carrots, and sweet potatoes use their roots for storage; lettuce, cabbage, and bulbs, such as onions and tulips, accumulate food in leaves; crocus, gladiolus, and potatoes in stems. The century plant and banana require more than a year to produce adequate amounts of food. The perennials need so much energy that they spend several years gathering sufficient amounts of food before they bear fruit. Once they start, they are able to continue to flower and fruit until they die. Some perennials are unable to gather enough to produce crops every season. The olive, some varieties of apples, and other fruits and nuts bear fruit every second, third, or fourth year because of this factor.

Plants have no mechanisms to control their temperatures like warm-blooded animals. These are, therefore, usually the same as that of the

surrounding air. Plants and plant parts that contain a large amount of water, however, tend to be cooler than the surrounding air. Cucumbers, watermelons, and many cacti are often quite cool on warm days. In winter, under direct sunshine, the shaded side of a tree will be much colder than the side exposed to the sun. Alpine and other plants growing in cold climes are scrubby, small, and stunted because they do not receive much energy from heat. Southern plants have accustomed themselves to a long growing cycle and need more heat than northern ones. In the north, evergreens conserve energy by remaining green and therefore are able to manufacture food whenever the light and temperature are favorable.

Too high a temperature causes a disturbance in the cells. The proteins coagulate and the plant may die. High temperatures increase the rate of transpiration, which may get so high that the plant will reach the permanent wilting point and perish. They also induce plants to grow rapidly. This may cause the structures to be weak, susceptible to disease, insect attack, and injury that may prove fatal.

Winter is not a recurring catastrophe to the vegetation of temperate- and cold-climate plants, but a necessary stimulus that they must experience before renewing growth. Some plant parts, like seeds, buds, bulbs, and roots, have become so accustomed to cold that they must be subjected to low temperatures before they will start to grow. Just as warm-climate plants experience dry spells that bring them into dormancy, so temperate- and cold-climate plants must experience cold spells.

Plants escape cold injury by finishing their life cycle before frost occurs; by accumulating food in the form of oils and starches, which contain less water; or by becoming dormant, a process that is very mysterious. The only thing we know about dormancy is that less water is present when a plant or plant part is in that state. Resistance to cold then depends mainly on the amount of water and the state of growth. Plants are able to withstand frost when dormant. They are very susceptible to cold injury when they are growing rapidly and when the fruit starts to mature.

The drier the plant or plant part, the better it can withstand cold. Bud scales, cork, waxy coverings do not protect the plant from cold directly. They make it less susceptible to frost by preserving the correct water relationships in the plant.

We can artificially produce a state of resistance to frost injury by a process called "hardening." This is usually practiced on young seedlings that were started indoors or in warm places. They are put outdoors in shelters when it is a bit cold and are allowed to suffer slightly from lack of water. The cells will then be able to retain water in a colloidal state, enabling the plant better to withstand low temperatures.

Wind

When the air is heated, it expands and becomes light. Cool air, which is heavier, will flow in, as nature cannot endure a vacuum. Just as water seeks its level by flowing downhill, so air will move from a region of high pressure to one that is lower in order to even things up. Owing to the many complicated factors that cause agitations in the air, it is always on the move. In many places on the earth's surface winds have a tendency to flow from one region to another. These are called prevailing winds. Many large areas of land experience certain climatic effects that are caused by these.

When prevailing winds come from hot desert areas, the lands that they pass will be heated. When they come from cold climes, they will bring freezing temperatures. From large water areas they will carry water vapor. If dry they will have a tendency to take up moisture. These increase evaporation tremendously, and if of long duration, do a great deal of harm. So winds influence plant growth to a remarkable degree.

The velocity or speed of the wind increases with elevation, because there are not so many obstructions at higher altitudes as there are near the ground. The top leaves of trees transpire much more than those of lower growths. Small plants are less affected by winds than tall ones.

Winds of high velocity damage plants in many ways. They bend branches and trunks permanently. They break twigs, branches, and trunks, and uproot trees. Their effect is so great that plants growing in windy places are distorted by being one-sided and unbalanced. The olive trees growing on exposed hills in Mediterranean regions suffer so much from dry, hot prevailing winds that they are small and gnarled even though several hundred years old. Crops are often ruined by strong winds. Cereal plants are bent down, flowers and fruits blown off.

Winds that carry soil particles cut into stems, branches, and trunks to such a degree that these become smooth and worn down. They cut young tender plants and leaves into ribbons. If there is no plant cover over land areas, the winds can carry away the rich topsoil. Such wind erosion becomes catastrophic, as in the "dust bowl" of our central states a few years ago.

Some winds are beneficial, especially those carrying a wealth of water vapor from lakes, seas, and oceans. Prevailing winds of this type permit the growth of water-needing plants in very dry areas. The giant redwood trees can thrive in central California because they receive a great deal of heat and a tremendous amount of moisture brought in from the Pacific Ocean by prevailing winds. Pollen grains, spores, seeds, fruits, and other propagating units are distributed by winds over wide areas. Sometimes wind is very helpful because it dries out moisture, and thus

low forms of harmful organisms are unable to grow and damage stems, leaves, flowers, and fruits.

Humidity

The air gathers moisture by the evaporating power of heat and by dry winds that gather water molecules from moist surfaces such as leaves, the ground, and bodies of water. This moisture in the air in the form of water vapor is called humidity. It is very important because it is this humidity that determines whether a locality is damp or dry. It therefore controls the rate of transpiration of plants and determines whether or not a certain plant can live in that locality.

The air, at a specific temperature and pressure, can hold just a certain number of water-vapor molecules. As the air acts like a sponge, the lower the relative humidity, the more water vapor it can absorb.

When the relative humidity of the air reaches the saturation point, the water vapor has a tendency to collect and condense around the small particles of dust, spores, and other substances present. These form clouds (Fig. 22).

When these clouds come in contact with a layer of air that is holding as much water vapor as it can, or when they are cooled so much that their holding power is decreased, the water will be forced out and fall to earth as rain, sleet, snow, or hail. Snow comes to us from the frozen solid clouds. Ten inches of snow usually contain the same amount of water as one inch of rain. Snow is particularly beneficial because it acts like a blanket, protecting the earth and vegetation from frost. In addition, it is rich in nitrogen in a soluble form.

When the air contains a great deal of moisture during a warm day, and it gets cool in the evening, water will be forced out and deposited as dew on the surface of plants and other objects.

Light

The light that filters down to earth through the thick layer of air that encircles the world, the composition of that air, and its temperatures, movements, pressures, and humidity have a tremendous individual and collective influence on plants. Together they make up several climatic patterns. Plants, like animals, differ in different climates. Some, like the pines, grapes, and roses, have a wide climatic range; others, such as rubber trees, sugar cane, rice, and pineapples, are fitted for life in only one climate. On the basis of varying climatic conditions, especially temperature and moisture requirements and soil conditions, five principal types of vegetation have developed on the earth's surface.

Arctic flora, which consist mainly of lichens, sedges, mosses, grasses, and other dwarf plants, are able to exist in the cold polar regions (Fig. 23). The arctic lands, called tundra, are usually flat, low-lying swamps

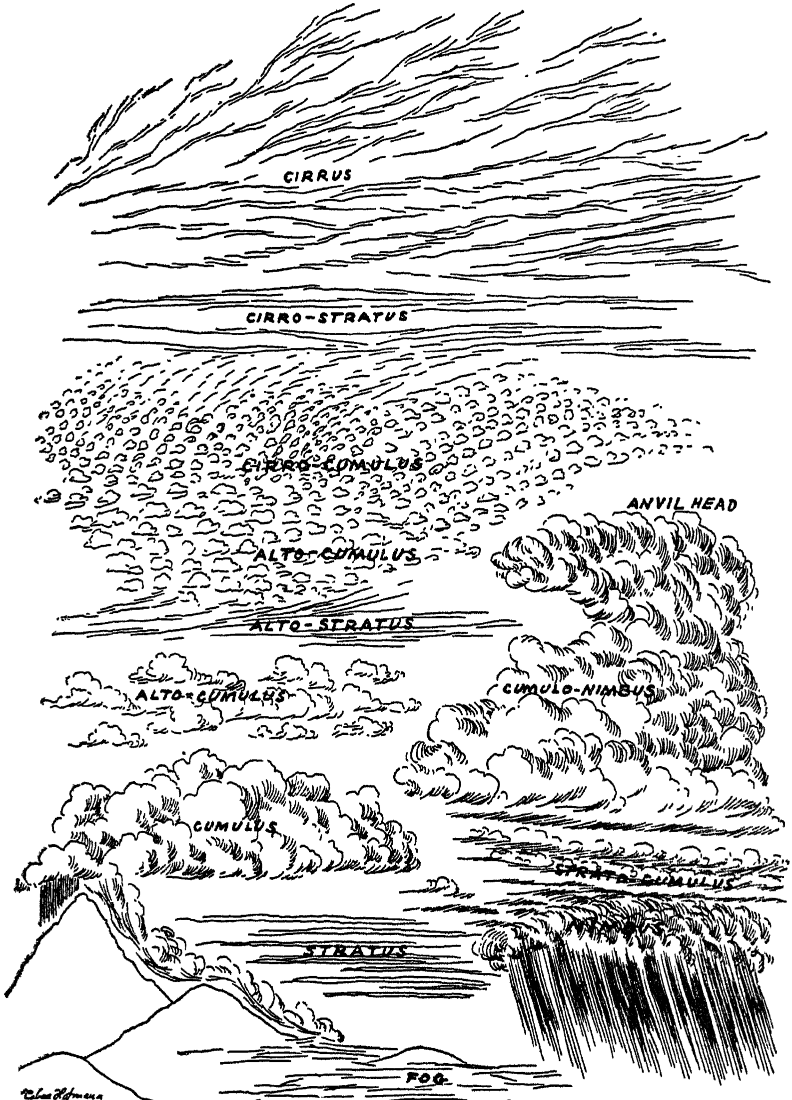


Fig. 22. Cloud formations

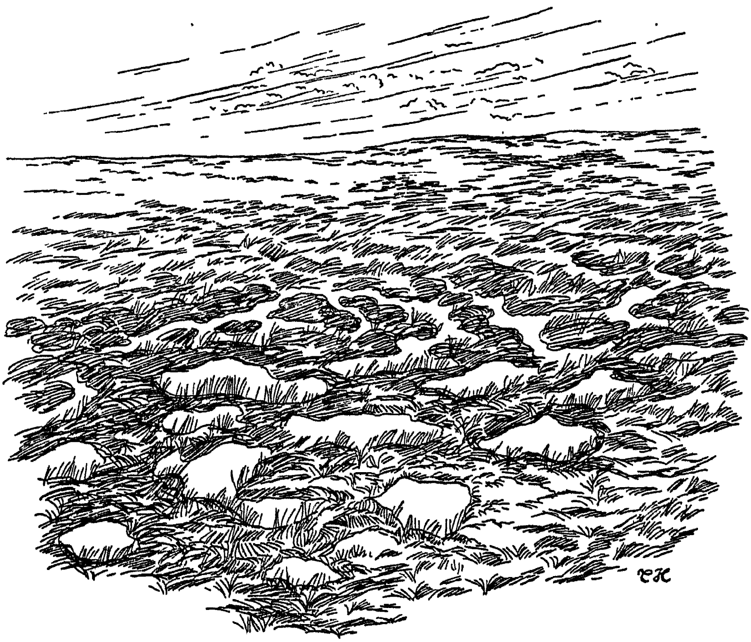


Fig. 23. Arctic landscape in a tundra region

in summer and frozen deserts in winter. Practically the same types of plants that grow in the arctic zones are able to survive the bitter cold on high mountaintops just below the snow line. High mountain plants are called alpine flora (Fig. 174).

The temperate zones vary greatly in their temperatures, winds, humidities, soils, winter snows, and summer droughts. They have wide seasonal changes marked by rainy spring, warm summer, cool fall, and frosty winter. The length of day varies with the seasons, being about nine hours in winter and fifteen or more hours in summer. These lands support a wide variety of vegetation. When temperate conditions are most favorable, very large trees develop. In sections where the winters are very cold and seasonal droughts occur, soft-wood, needle-leaved evergreens or broad-leaved hardwood trees that lose their leaves in the winter months form large forests. Where the winds are very strong and the rainfall is scanty, vegetation is restricted to bushes and grasses, as in our central plains. Our wheat, corn, rye, barley, forage crops, grasses, peanuts, flax, hemp, tobacco, potatoes, beet sugar, and many of our garden fruits, vegetables, and flowers are grown in the temperate regions.

The subtropical zones, such as the Mediterranean Basin, most of

Mexico, and southern California, enjoy damp mild winters, and experience hot dry summers. Our Gulf States and other semitropical regions have heavy rains during the summer months, and dry warm weather in the winter. Rice, citrus fruits, avocados, yams, figs, dates, tobacco, olives, cotton, peanuts, and mulberry trees for silk culture are some of the important economic plants cultivated in these warm lands (Fig. 24).

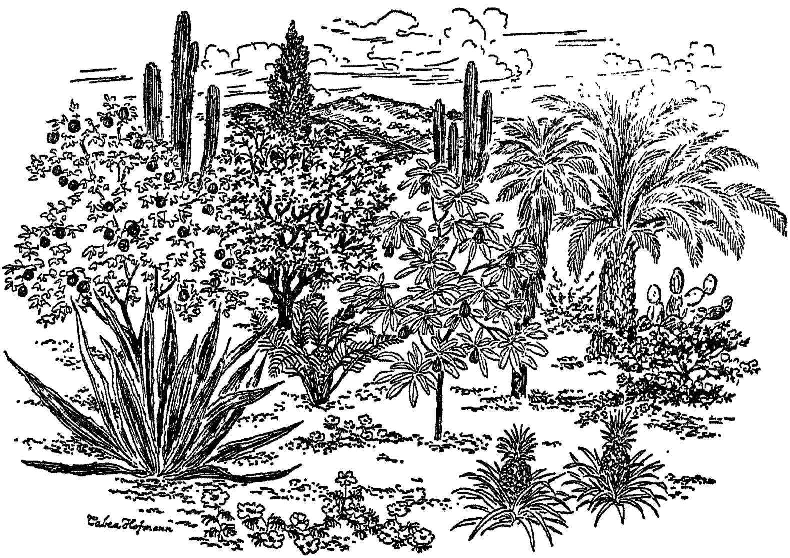


Fig. 24. Some typical subtropical plants. From left to right: Foreground, century plants, anemones, pineapples; center, orange, olive, Florida arrowroot (Zamia), guava, royal palm, rose, cactus; background, cactus, cypress, date palm

Very warm temperatures and almost continuous rains occur in the tropics. The tropical rain forest regions of the Amazon River Valley, the Congo in Africa, parts of Central America, and the West Indies experience the best climatic conditions for plant growth, but because of the heavy rains the soil is usually very poor. Tall trees and climbing vines form a heavy, tangled, evergreen, jungle vegetation that is almost impenetrable. The overhead canopy is so dense that hardly any sunlight reaches the forest floor, which is covered with many ferns, small bushes, orchids, and parasitic plants (frontispiece).

The tropical savanna regions have alternating dry and wet seasons. They are situated just above and below the true equatorial tropics, in India, Brazil, Africa, and Indo-China. Most of the plants that grow in

these regions lose their leaves during the hot, dry, windy seasons. The trees are usually spaced wide apart, and the ground is covered with heavy grasses. Among the most important crops produced in the tropics are rice, lumber, rubber, sugar cane, bananas, spices, drugs, jute, cacao, coconuts, palm oil, coffee, and tea (Fig. 25).

Fig. 25. Landscape in a savanna region

Warm regions that receive very little or no rainfall are covered with dry, shifting, salty sands, and are called deserts. These areas experience very hot temperatures during the daytime when the sun is shining. When the sun goes down the temperatures may drop almost to the freezing point. Many cacti, a few grasses and scrubby bushes, and some very small annual flowering plants are able to exist in some desert areas. The largest desert area in the world extends across all of North Africa from the Atlantic to Egypt, and continues across the Red Sea through Arabia, Iraq, Iran, and Afghanistan to central Asia. Other large regions exist in northwest India, central Australia, and certain sections of North, Central, and South America. Some desert areas are marked with many small water pockets, around which certain plants are able to thrive. Such a localized dense vegetation is called an oasis. Some parts of North Africa, Egypt, Iraq, northwest India, and certain desert areas of the United States, which are irrigated by natural or artificial rivers, support a very rich vegetation. Among the most valuable crops culti-

vated in watered deserts are "off season" fruits and vegetables and dates, cotton, and alfalfa (Figs. 26, 181).

Fig. 26. Scene in the Sahara Desert

Part II: The Natural History of Plants

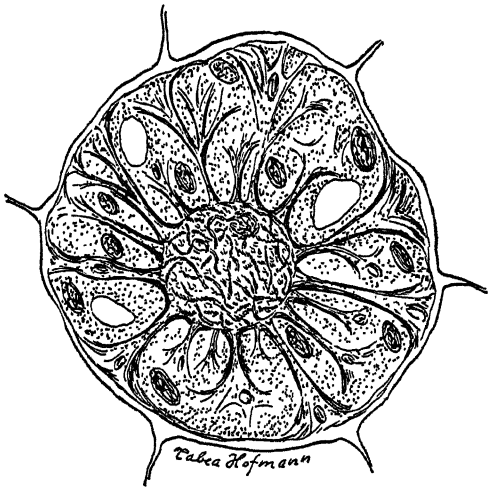


Fig. 27. A young, active plant cell

11. THE MOST WONDERFUL SUBSTANCE IN THE WORLD

NOTHING that lives is alive in every part. In all living organisms, no matter how small, and in every individual cell of the most highly developed plants as well as animals, there are living and nonliving portions.

In the physical world, protons, neutrons, and electrons unite to form atoms. The atoms combine in a tremendous variety of ways, producing many different kinds of molecules. The distinctive property of living matter is due to the mysterious combination of these molecules, which by themselves do not show any of the mystical powers of life. Life is the product of organization, and probably emerged from the interactions of these molecules.

The substance in which the action of living takes place is called protoplasm. The term, which comes from two Greek words meaning first form, is apt because protoplasm is the primary and physical basis of life. Protoplasm is a wonderfully delicate and complicated colloidal mechanism. It is made up of a mixture of extremely fine, solid particles of various substances held together in chains or groups of molecules that are suspended in a liquid. Countless ions of different salts maintain the unique qualities of the living medium. The proteins are

the essential architectural bodies. Certain sections of the structural framework are made up of special forms of carbohydrates. The energy needed for the many activities continuously taking place is furnished by oxidation of the sugars. The starches contain stored energy for future use. The fats serve as protective coverings and are a source of concentrated reserve food and energy.

The most characteristic property of living matter is its ability to undergo change. Foods, together with other combinations of elements, are worked over, built up, and molded into protoplasm. Part of the living substance is continuously being broken down into nonliving matter, causing the release of the stored energy which is used by the organism in its life activities. This fundamental process involving the perpetual transformation of matter and energy is called metabolism.

All the phenomena of life are a result of the work accomplished by protoplasm. The activities taking place are strictly determined and limited by the internal properties of this extraordinary colloidal organization, and by the external conditions that influence its transformations. There is a regular order and chain of reactions taking place, each progressive step being determined by something that happened before.

No adequate way has as yet been found to study protoplasm in its living state. When it is disturbed, its delicate structure is broken apart and it is killed. We then have a mass of inert chemical materials that show none of the properties of life, because only the special arrangement of the molecules grouped in some unknown architectural fashion brings forth the action that we call living.

We do not know how the very first bit of protoplasm came to be. Some scientists think that life originated in the sea because protoplasm contains the same salts, in much the same proportions, that are found in sea water. All forms of life develop as a result of the formation of new living matter, which, as far as we know, can be manufactured only by protoplasm already in existence.

Basically, the protoplasm of every different kind of organism is the same. The varied properties of the hundreds of thousands of different kinds of animals and plants and their parts are due to very slight differences in the make-up of their protoplasm. These differences can usually be detected only by the products that the protoplasms manufacture.

The smallest bits of living matter that can accomplish all the necessary work of life—transforming matter and energy—are called cells (Fig. 27). In very low, exceedingly small organisms, the entire being is made up of just one continuous mass of protoplasm (Fig. 38). In this type of living organism the single cell is the working entity. It can contract and expand; rest and move; take in various gases, liquids, and solids in solution and change them; expel certain waste materials;

react to changes taking place in its immediate environment: conduct the effect of these changes to other parts of its being; and it can grow and reproduce itself. In multicellular plants and animals, the protoplasm is divided into myriads of cells. These are so constructed and arranged that each individual cell is a part of and contributes to the welfare of the whole plant.

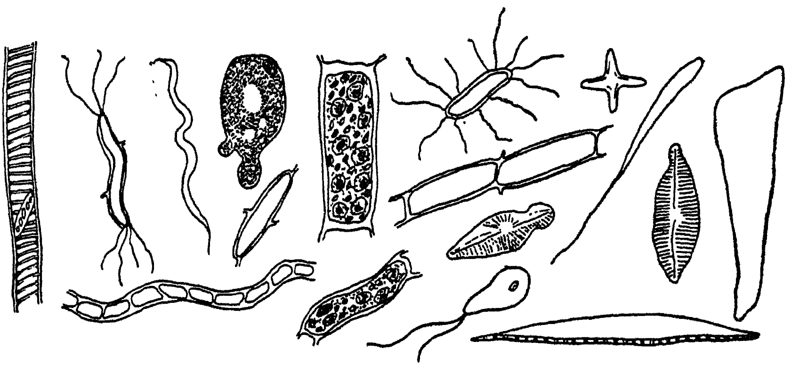


Fig. 28. Differences in form and size of plant cells

There is a wide range in sizes of plant cells (Fig. 28). The diameter of most is so small that an ordinary, full-grown, single, geranium leaf contains about one hundred million cells, and a medium-sized potato is made up of more than three billion cells. Organisms such as the bacteriophages are so tiny that we are unable to see each individual cell, even with the most powerful microscope. The largest plant cells, such as some cotton, linen, and hemp fibers, may attain a length of ten inches or more.

Although the structures found in different cells are far from uniform in kind, size, number, form, and function, most cells of green land plants contain nucleus, cytoplasm, membranes, and cell wall.

Nucleus

The nucleus is a sphere- or oval-shaped dense portion of the protoplasm usually found near the center of the cell (Fig. 29). There is generally one nucleus per cell, although some cells contain many nuclei and in a few types no visible nucleus is present. The nucleus is composed of an almost clear liquid sap having storage spaces where reserve foods are kept. It contains a network of granular materials called chromatin. At cell division these arrange themselves as genes in chromosomes (Figs. 30, 40). Almost all nuclei also contain a nucleolus. This is a small, dense mass of matter the function of which is not clearly understood.

The genes are the vital hereditary controlling factors in the life of an organism because they determine, to a great extent, the shape, size, structure, and work of the cell. They are permanent bodies with individual qualities of their own. The genes generally reinforce and help each other. Usually several genes are necessary to control a particular activity and to bring forth a certain feature. However, it is possible for certain single genes to affect one or more characteristics. Under normal circumstances, outside environmental conditions and the changes taking place in the cell during its life activities do not usually affect the genes. Unless they are altered by some extraordinary event, they retain their original characteristics and are passed on, unchanged, to the new generation when the cell divides.

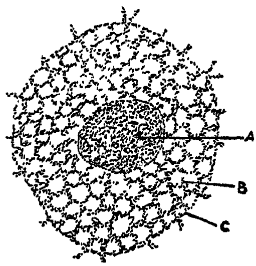


Fig. 29. A typical nucleus: (a) nucleolus, (b) chromatin, (c) nuclear membrane

The genes are arranged as independent units on strings, much as individual beads make up a necklace. Each string of genes in its matrix is called a chromosome, and each chromosome may be composed of a few to several thousand genes. We can compare each gene to a worker, and can think of every chromosome as being made up of a crew of specific workers. Normally, each gene has its definite place on a particular chromosome. Each kind of plant and animal has its specific number of genes in each chromosome. A certain number of chromosomes makes up a complete set. The number of chromosomes in a set varies in different kinds of plants and animals, and may be anywhere from two to over a hundred. Whether a few or many chromosomes are needed to

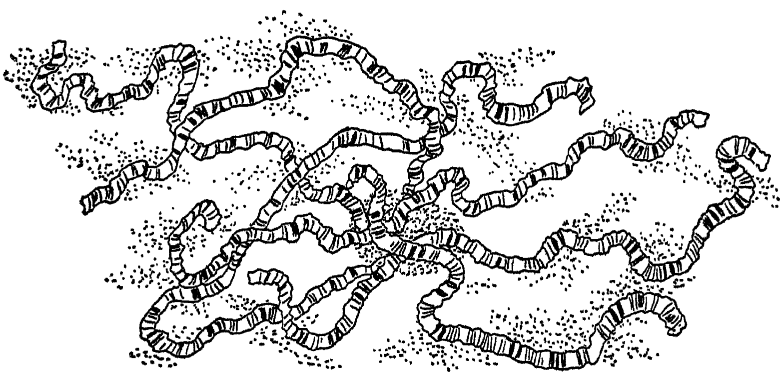


Fig. 30. Arrangements of genes in chromosomes

make up a set seems to be incidental, and as far as we know has no special meaning or significance. Some low forms of seaweeds and fungus growths have sets consisting of but two chromosomes. Corn plants have 10 to a set, humans have 24, the crayfish has 100, and the horsetail plant 141. The bodies of all normal higher kinds of plants and animals are made up of cells usually containing two more or less similar genes for each type of activity and for every characteristic. They therefore have two sets of chromosomes. For example, in corn plants we see 20 chromosomes, as one set consists of 10. In humans every normal body cell has 48 chromosomes because each set consists of 24.

The nucleus is protected by a thin covering called the nuclear membrane, which separates it from the rest of the protoplasm. This membrane permits the interchange of materials between the nucleus and the other portions of the cell.

Cytoplasm

All the protoplasm that lies outside the nucleus is called cytoplasm (Fig. 31), which is a nearly transparent gluelike fluid. It is this mate-

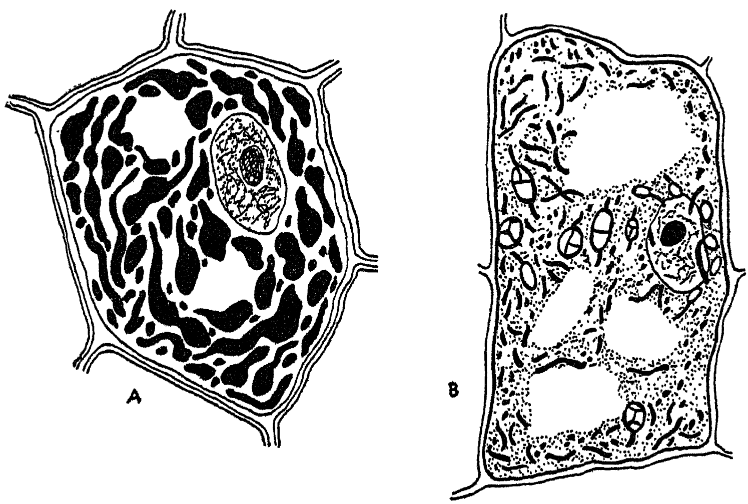


Fig. 31. (a) Cell stained to show alkaloids, fats, glucocides, and other materials; (b) cell stained to show carbohydrates, proteins, chondriosomes, and other substances

rial that does the actual work of changing matter and energy. Although the genes control the activity of the cytoplasm to a marked degree, various other special bodies such as the enzymes, pigments, hormones, and vitamins, as well as reactions caused by changes in the environ-

ment, greatly affect the life of the cell. Changes in light, temperature, and water relations, contact with some object, the pull of gravity, differences in concentrations of gases, and various chemical agents are all important stimuli that cause responses in the cytoplasm.

In some cells the cytoplasm is very fluid, in others it is thick and gummy. When fluid it does not remain stationary within the cell chamber but flows from one part to another part of the cell. In some cells it moves as a thin stream along the outer walls. In other kinds of cells the inner portions move around and around, while the outer parts, lying along the walls, are stationary.

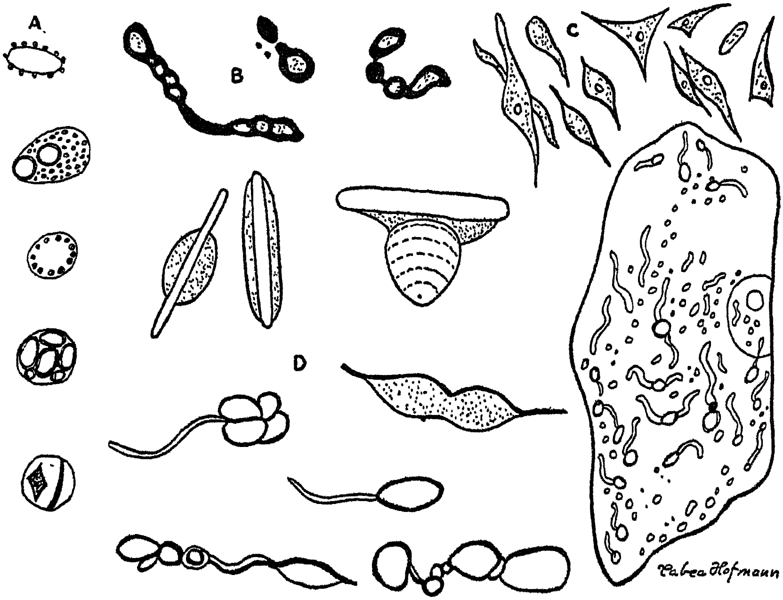


Fig. 32. Plastids: (a) chlorophyll bodies, (b) leucoplasts, (c) chromoplasts, (d) chloroplasts

Within the cytoplasm there are found various kinds and numbers of living structures called plastids (Fig. 32). The number and type of plastids present depends upon the work the cell does. Many plastids are manufacturing and processing enzymes. Usually there are three different types. The chloroplasts contain chlorophyll and are the green manufacturing centers; the colorless leucoplasts build up starch grains from sugars; and the red and orange chromoplasts have various other functions. There are also certain granular or rod-shaped bodies called chondriosomes (Fig. 31), of which some are living, others are not.

The nonliving bodies in the cytoplasm are called inclusions. These

are composed of various types of foods that may later be converted into living matter, or waste products of all kinds. Many of these inclusions are responsible for characteristic tastes, colors, aromas, burning sensations, and other characteristics. Some of the most common types of inclusions are starch grains, oil drops, protein bodies, crystals, resins, latex, organic acids, alkaloids, aromatic materials, and vacuoles.

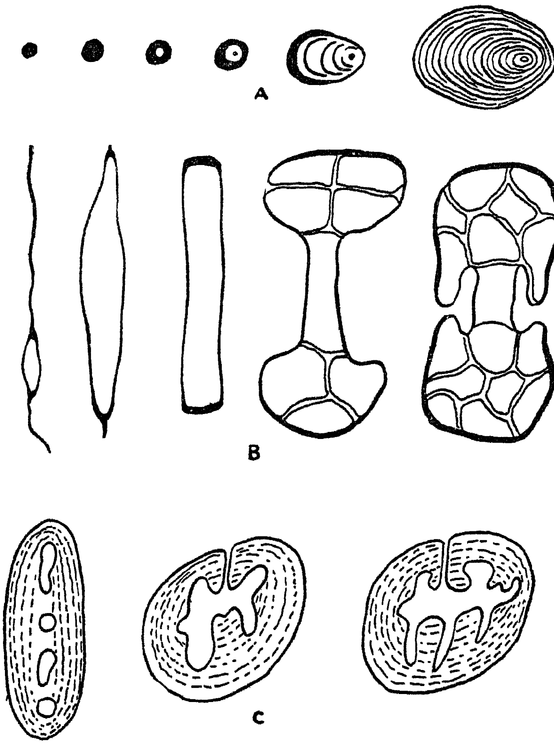


Fig. 33. Growth of starch grains in: (a) potato tubers, (b) spurge, (c) wheat grains

The starch grains (Fig. 33) are made up of the accumulations of insoluble carbohydrates stored as reserve foods. Concentrated forms of food and energy are found in the oil drops. Some poisonous waste products are unable to pass out through the membrane, and they accumulate in the cytoplasm. They are made harmless by being chemically combined with calcium (Fig. 34). These accumulations form crystals, oil drops, and other substances of many kinds and shapes.

The most important inclusions are the vacuoles (Fig. 35). These are various forms of watery solutions, commonly called cell sap, containing

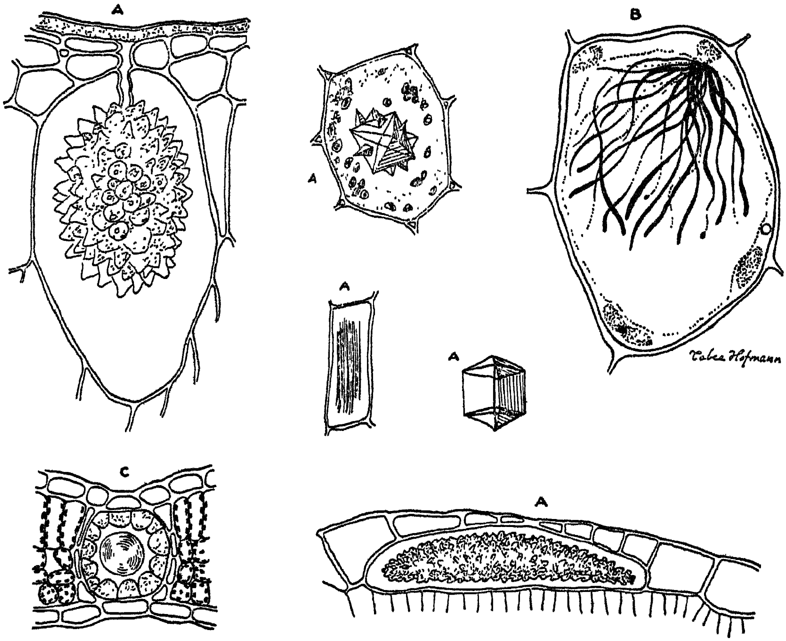


Fig. 34. Inclusions: (a) calcium crystals, (b) iodine in kelp, (c) oil reservoir in St. Johnswort

sugars, salts, pigments, and different kinds of acids. The vacuoles are important storage reservoirs and partial regulators for the entry and exit of different materials from cells. When a cell is young, the vacuoles are small and separate bodies, each one being individually enclosed in its membrane. As the cell ages, these inclusions grow in size and fuse together, and when the cell reaches maturity there is generally one large vacuole.

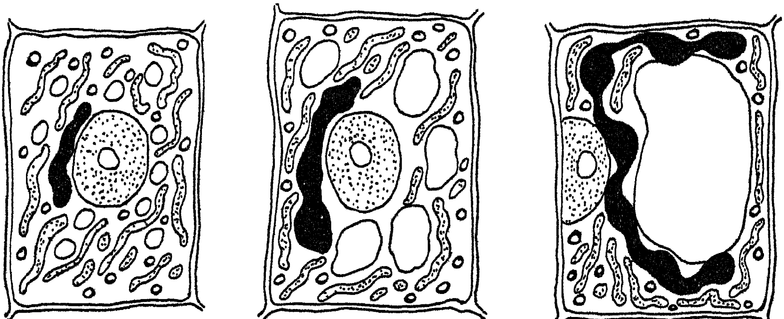


Fig. 35. Growth of vacuoles

The entire protoplasm of each individual cell is covered by a thin living membrane. The structure and composition of this delicate covering is such that, unless injured, it permits the passage of dissolved substances into the cell by osmosis and other little-known processes.

Cell Wall

The protoplasm in each cell of higher forms of plants manufactures and secretes its individual wall. This cell wall (Fig. 36) is a nonliving, rigid, colloidal film that surrounds and protects the living protoplasm. In young, newly formed cells the wall is made up of an exceedingly thin, sticky material called pectin. As the cell grows and ages, layers of cellulose are added and the wall becomes strong enough to support the cell and the plant as a whole. In addition to pectic and cellulose substances, cell walls usually contain minerals, tannins, waxes, oils, resins, and other materials. Most changes in the forms and functions of cells are due to the various modifications of their walls.

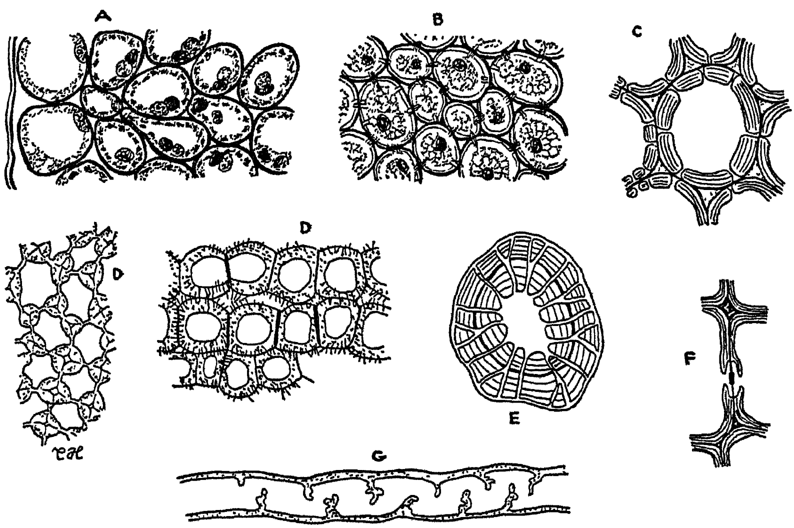


Fig. 36. Cell walls: (a, b, and c) gradual thickening of walls by addition of layers of cellulose, (d) Collenchyma tissue, (e) stone cell, (f) pit, (g) disintegration of cell walls to form tubes and hollow stems

When the cell wall is thin it permits the free passage of solutions. Thick cell walls frequently possess tiny thin areas, called pits, that permit water and dissolved substances to diffuse from one cell to its neighbors (Fig. 36-F). Many walls have small openings through which strands of protoplasm extend from one cell to another. By this means

the organic unity of the whole plant body is made possible. Both dissolved nutrients and stimuli circulate freely from any cell to any other unit (Fig. 48).

The thin pectic material of the original cell wall between two cells often splits open, forming spaces between the cells. These intercellular spaces are filled with air and form a narrow connective system of canals that extend in all directions. Sometimes entire cells as well as their walls break down and form cavities (Fig. 36-G). This often takes place when growth is uneven, and hollow stems result.

As there are a great multitude of different types of living organisms in the world, and as all the larger individuals are made up of trillions of diverse cells, we can readily visualize that there are all kinds, sizes, shapes, and structures of these units. The property of each cell depends upon its parentage, the influence exerted by its nucleus and other controlling agents, its past history, age, position on the plant body, and the influence of various environmental factors.

Just as some substances in protoplasm are more active than others, some cells are more active than other cells. Each cell and the work it performs is essential for the well-being of all the other cells, and each is an integral unit upon which the welfare of the entire plant depends.

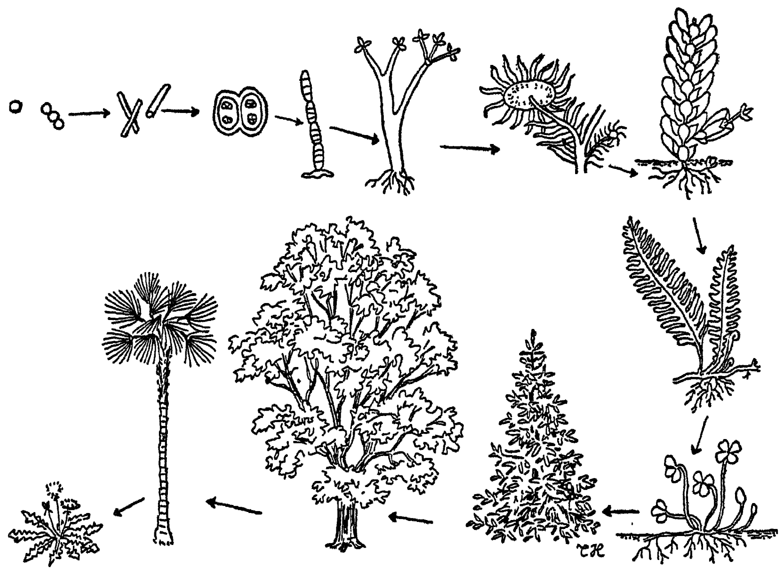


Fig. 37. Evolution of plant life from simple beginnings through mighty trees to highly evolved, very complicated, annual-flowering plants

12. FORMATION OF THE CELL CITY

ORGANIZATION, in the form of life, does not disappear suddenly below the level of the cell. There is a continuous series of more and more complex structures starting with the simplest atoms, and ranging from molecules, colloids, protein bodies, enzymes, and genes through border-line structures, such as the viruses, to clearly defined living organisms. Likewise there is a vast progression of plants ranging from the simplest tiny single-celled organisms without any definite form and structure through many intermediate kinds up to the most highly developed flowering land plants made up of innumerable specialized cells.

The first and lowest degree of living organization is still unknown to us. The tiniest detected living bodies are somewhere on the border line between nonliving enzymes and definitely proven living bacteria. The lowest of the borderline organisms so far detected are so small that we are unable to see them even with the most powerful microscopes. They are called bacteriophages because they have the ability to dissolve and absorb bacteria. Fluids containing these bodies can be ex-

tracted from one organism and transferred to another one where they are able to continue their activities, grow, and multiply. Specific bacteriophages that act on certain types of bacteria and have little or no affect on others have been isolated.

The smallest and simplest organisms that have actually been seen are called filtrable viruses. They are so named because they can be separated, or filtered out, from fluids in which they live, by the use of special screens made of porous earthen containers. We do not know how these viruses are constructed, but we do know that they are the cause of terrible plant, animal, and human diseases. Our common colds, measles, smallpox, and polio are due to the activities of specific viruses. Many animals, as well as over one hundred different kinds of plants, are attacked by these living organisms.

Some very primitive forms of life, such as the slime molds and certain other fungus growths, have thousands of nuclei and are not organized into cells. They are slimy, fleshy, or cottony naked masses of protoplasm with no definite size or outer form. When sufficient food and proper working conditions are present they may grow to be several inches long and as much as half an inch thick.

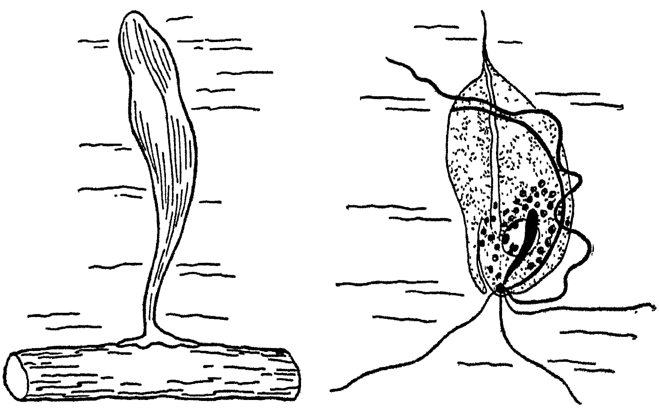


Fig. 38. (Left) Sea lettuce (Ulva), a typical, simple, attached, underwater benthonic plant; (Right) swimming algae (Chlamydomonas), a complicated, free-swimming, single-celled organism

The simplest definitely organized cells are in the shape of spheres. This most economical form of construction is found in many kinds of living organisms, and in such organs as spores, pollen grains, seeds, and fruits. Man often uses small or large sections of spheres, which we call arches or domes, in the construction and roofing of many of our tunnels, large buildings, and other structures. By this means a large surface is

well supported with the use of the minimum amount of material, and therefore is of light weight.

In order to increase its working surface an organism must elongate its body and assume the shape of an egg, cigar, tube, flat round disc, or thin flat ribbon. Many cells, tissues, and organs have cylindrical shapes because they afford a large working area coupled with great strength and the most economical use of supporting materials.

When a sphere is stretched out into a long tube, we call the cylinder so formed an axis (Fig. 38). This axis has two ends or poles. Organisms having two distinct poles may develop at one pole either tiny moving hairs that act as tails and provide a means of locomotion, thus enabling them to swim about in a liquid, or a holdfast that anchors the organism in place, leaving the other end free to grow.

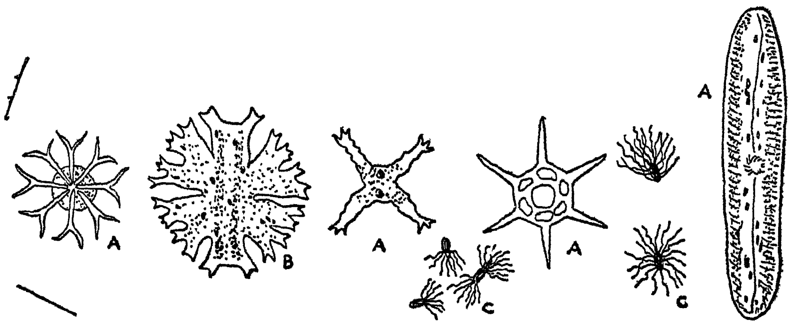


Fig. 39. Single-cell plankton: (a) diatoms, (b) desmids, (c) bacteria

The most highly developed single-celled plants are very complicated and much more highly organized than many low forms of multicellular vegetation (Fig. 39). These types of plants are able to swim about in the liquids in which they live, in search of warmth and light and away from cold and darkness. Many thousands of such swimming single-celled organisms may unite temporarily in colonies to form grapelike clusters, chains, discs, or spheres. Each single-celled organism in such an association retains its individual characteristics, and sooner or later swims away to continue its independent life.

All but the very simplest active growing cells increase themselves by typical cell division (Fig. 40). This division of a growing cell into two daughter cells is accomplished by an exacting process in which there is a definite sequence of events. It is one of the greatest wonders in the entire domain of living nature. It is essentially the same for all active cells, whether they exist as single-celled independent individuals or are units making up the multicellular bodies of plants or animals. The process consists in the exact splitting into two parts of every living

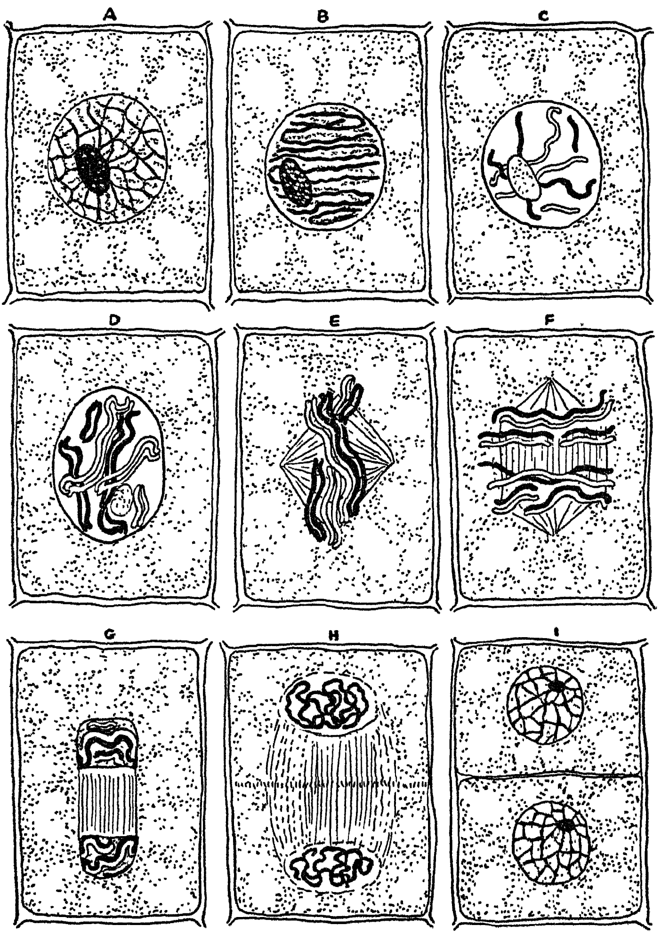


Fig. 40. Mitosis—typical cell division: (a) nucleus before division, (b) the chromatin forms a long coiled thread, (c) chromosomes assume definite number and form, (d) each chromosome splits into two lengthwise, (e) the split chromosome halves arrange themselves in the center of the cell, (f) the chromosome halves separate, (g) two complete sets (3 chromosomes in each set) go to one pole, and the remaining two sets go to the other pole, (h) reorganization of the two new nuclei, (i) chromatin network is formed and cell wall separates the two new daughter cells.

body in the cell, and the distribution of each half into daughter cells. This typical process of cell division, called mitosis, takes from about thirty minutes to several hours.

When the cell is about ready to divide, the scattered strings of genes in the nucleus become attached into a long coiled thread (Fig. 40-B). This thread then breaks up into the variously shaped chromosomes (Fig. 40-C), which then arrange themselves in the central part of the cell. Next, each chromosome splits lengthwise into two parts, doubling each gene and every chromosome (Fig. 40-D). A cell that normally has its genes grouped into six chromosomes has twelve at this stage of division. Instead of having two genes for each characteristic, it now has four. At this point all the other living bodies in the cell likewise divide in two. The membrane of the nucleus disappears and the chromosomes arrange themselves in a double row along the middle of the cell (Fig. 40-E). Half of all the chromosomes, that is, two complete sets, and half of all the other living portions now move away from the center toward one end of the cell. The other two sets of chromosomes and the other half of all the other living portions moves to the other end of the cell (Fig. 40-F). When each group of bodies has moved sufficiently apart, a wall is formed across the middle of the cell, dividing it and all the living bodies into two parts, each with its own nucleus and cytoplasm (Fig. 40-G). Each new cell now contains the exact duplicate of the original six chromosomes, and the same number of all the other living bodies (Fig. 40-H). The chromosomes in each nucleus change into the irregular network of granules around which the nuclear membranes are formed (Fig. 40-I).

When the newly formed daughter cells separate, they continue life as independent single-celled organisms. The simplest types of multicellular plant bodies are formed when a cell is multiplied countless times by typical cell division, and all the cells remain permanently attached to each other. Division and redivision takes place again and again; the original cell becomes two, the two four, the four eight, and so on indefinitely as long as the plant remains alive and grows. In the lowest forms of life the cells are all similar and may arrange themselves to form various kinds of structures. These types of plants may be long thin silky threads or filaments (spirogyra) (Fig. 86), thin, flat, wide, leaflike blades (ulva) (Fig. 38), or magnificent netlike structures made up of an intricate system of interlaced thin strands of cells arranged in very beautiful patterns (lattice leaf) (Fig. 10).

In slightly higher types of vegetation, certain cells, while retaining their power of division, are changed slightly and enabled to perform specialized work to a limited degree. Some of the cells of the main axis send out side growths in different directions; these form small branchlike attachments that greatly increase the working surface of the plant body. These side growths contain many green chlorophyll bodies and specialize in food-manufacturing activities. Other cells form a skinlike gummy covering that protects the inner active cells. Certain cells absorb

water, gases, and mineral salts. Cells with thickened walls are added to the stem, affording better support for the added weight. Some of these primitive water plants resemble small trees (chondrus) (Fig. 98).

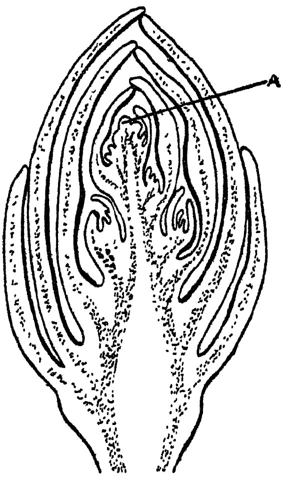


Fig. 41. Formation of secondary growing points in a bud, (a) meristematic dividing cells

The structure of the plant body becomes more complicated when the formation of new cells is restricted to certain areas called growing points (Fig. 41). These growing points consist of one or more special cells that retain their dividing power throughout the life of the plant. Such groups of cells are called meristems, which comes from a Greek word meaning divided or divisible, because every cell in a plant body originates as a daughter cell from the division of a meristematic cell. These cells have very thin walls and a large permanent nucleus, and are very rich in protoplasm. They reach full size and divide at a rapid pace even before attaining maturity because of their accumulation of water.

Growing points may be located in various parts of a plant body, and are always present at the tips of roots (Fig. 50) and the tips of branches of green land plants, where all the growth in length by addition of new cells takes place. Dividing cells called cambium form tissue when present inside of stems, roots, leaves, and fruits. Cambium cells form wood and other tissues, and increase the width of those organs. During the formation and growth of a plant, small groups, layers, or strands of dormant meristematic cells are sometimes deposited in various places. These may retain their dividing power for months, even years in some trees, and are able to start forming new cells at some later period when insects, diseases, wounds, or other irritations excite them to activity. Under unusual circumstances cells that have matured may regain their ability to divide and form new growth. Sometimes irritations, especially those caused by very small insects, viruses, bacteria, and other disease-provoking organisms, extremes in temperature, stray radioactive rays, great drought, and other factors may cause abnormal growths such as cankers, blisters, chimeras, and galls.

As the meristematic cells divide, daughter cells that lose this power gradually become permanent structures. These cells continue to absorb enormous quantities of water, and as their walls stretch out they increase from one hundred to one thousand times in size, especially in length. Their walls gradually increase in thickness, starch grains start

to accumulate as the amount of protoplasm diminishes, and as vacuoles filled with cell sap start to form and enlarge.

When such a cell reaches its maximum size it begins to undergo changes that transform it into a specialized cell. Once established, differentiation is completed, and it seldom changes again to another type of cell. These permanent cells may remain living and perform all kinds of work in the roots, stems, leaves, flowers, seeds, and fruits, or they may cease activity completely and become inner heartwood, cork, bark, spurs, or hairs. This transition may take from several days to many years.

Each type of cell formed by differentiation is adapted to serve a special function in the life of a plant. Cells of similar structure that together perform a special type of work are called tissues. The main tissue systems present in all green land plants are made up of covering, fundamental, conductive, strengthening, and secretion cells.

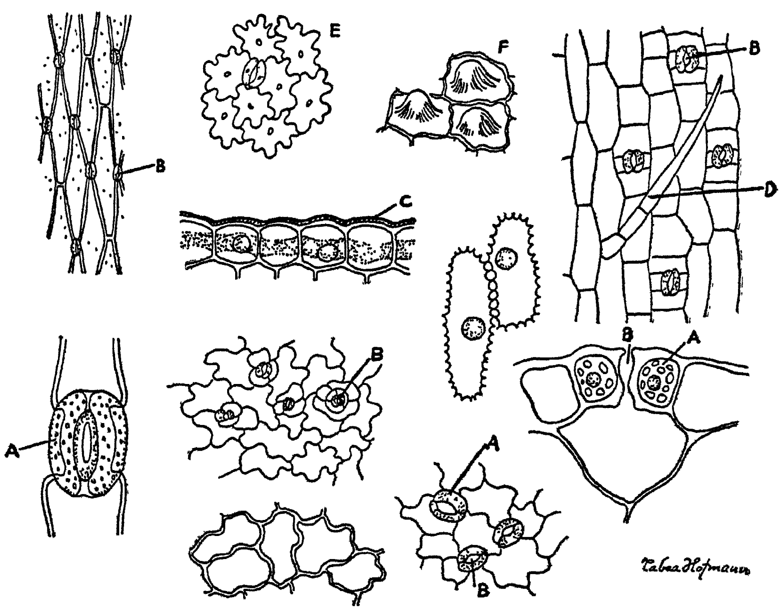


Fig. 42. Epidermis or skin cells: (a) guard cells, (b) stomata, (c) cuticle, (d) hair, (e) smooth surface, (f) rough surface

The cells that form a covering layer over the entire plant body and its leaves and fruits make up a tissue called the epidermis, which comes from a Greek word meaning skin (Fig. 42). This tissue is usually one cell thick and very firm. The outer walls of these cells are often covered

with a waxy substance called the cuticle, which permits rain water to flow off without disturbing the inner cells, and protects the inner structures from excess loss of water. Sometimes the waxy substance is spread very thickly over the cells and can readily be seen, as the "bloom" of grapes and plums, for instance.

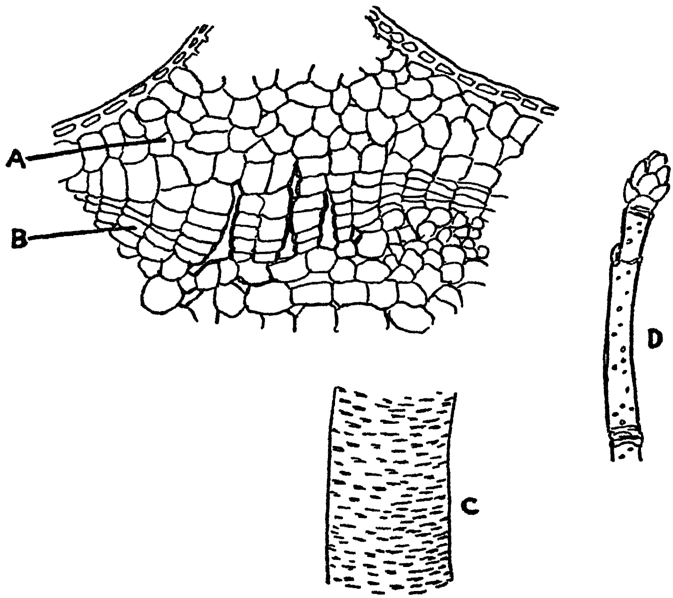


Fig. 43. Lenticels: (a) cork, (b) cork cambium, (c) white birch, (d) horse chestnut

Scattered in the skin cells, especially in leaves and in young stems, are small openings called stomata, which permit both the exchange of gases between the inner cells and the outside atmosphere and the evaporation of water from the inner tissues. When cork, bark, and other thick protective covering tissues are formed over older stems, small openings called lenticels are formed; these lead to the stomata of the original skin so that exchange of gases with the inner cells may continue to take place (Fig. 43).

The protective tissues covering the roots never contain stomata. The absorption of water and dissolved salts, as well as the release of carbon dioxide, various acids, and other substances, takes place through special outer absorbing cells situated near the growing points (Fig. 50). These may be very tiny elongated hollow tubes called root hairs.

The outer aerial surfaces of practically all plants are usually covered with all kinds of hairs (Fig. 44). These are either unicellular structures,

formed when a single cell of the epidermis elongates, or systems made up of several cells. They may be thick or thin, long or short, branched or simple, straight or curved, and may have rounded or sharp tips. Many are covered with deposits of silicates or calcium and are hard and brittle. The protoplasm in these hairs may be alive. When the living substance dies, the cavity is often filled with air, and the hair appears to be gray or white. Sometimes the hairs are compressed and form extremely long, very thin fibers like those of cotton seeds. The main functions of hairs are to prevent excess water loss by shading, serve as glands that excrete various substances, and act as parachutes to aid the migration of seeds by winds.

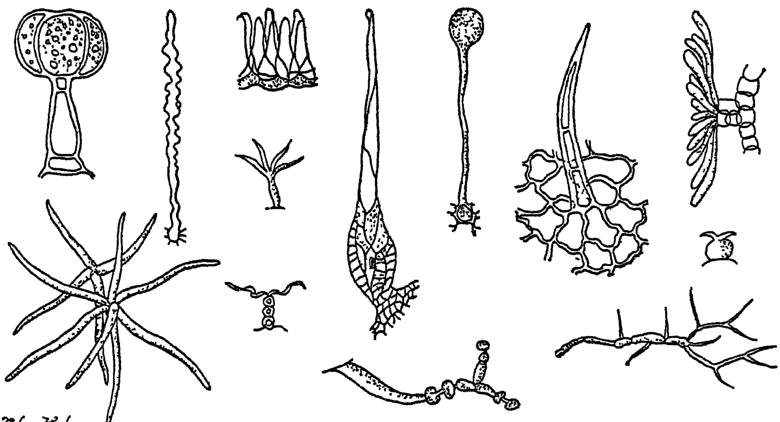


Fig. 44. Hairs and glands

The thick sharp spurs and thorns found on many bushes, trees, and fruits are not hairs but emergences formed by the combination of outer skin and inner body cells.

Many skin cells, as they age, develop very thick outer walls that use up and dry out the inner protoplasm. The walls collect a great deal of wax, tannins, and other substances, and change into cork and bark tissues, which afford excellent protection against mechanical injury, the evaporation of water, and the entry of harmful diseases and insects. The cork tissues of very large trees are formed by special strands of cambium cells. The cork oaks produce a very thick layer of cork tissue, which is cut and harvested to be used for many purposes, such as insulating materials, lifesavers, and bottle stoppers.

The fundamental body tissues (named parenchyma, a Greek word meaning connective tissue) are among the most important and widely distributed of all cells throughout the vegetable kingdom (Fig. 36-A).

All types of vegetation, even the most elementary forms of plant life, contain these cells. Practically the entire inner structures of roots, stems, leaves, flowers, and fruits that are not woody or fibrous are made up of parenchyma tissue. All of the most important manufacturing and processing activities take place in these cells. Most of the reserve food and water is stored here. Their protoplasm is very much alive and their vacuoles are filled with many nutritive elements and are very active. The many openings in their thin walls facilitate the movement of materials from cell to cell. Large spaces between these cells provide an excellent ventilating system, which is of paramount importance for the circulation of the gases and some liquids that they need for their many activities.

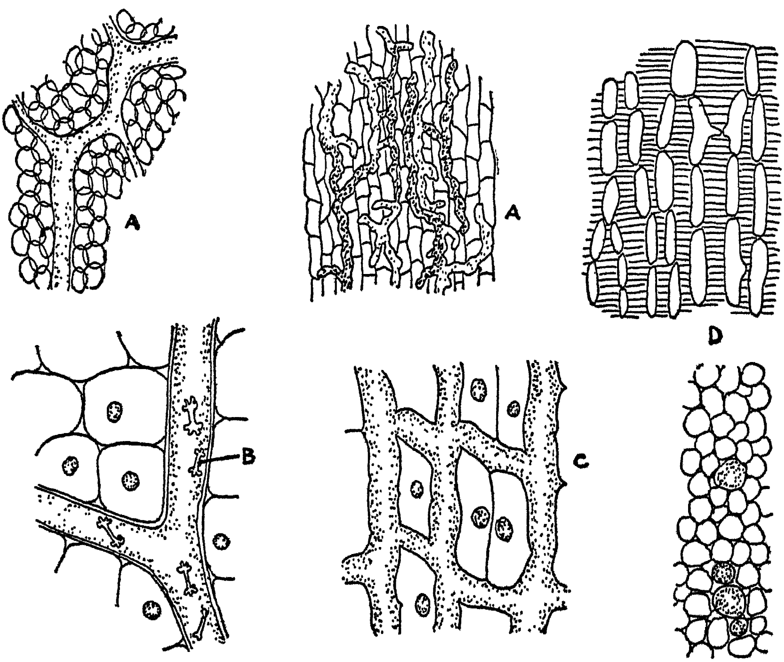


Fig. 45. Secretory canals: (a) latex canals, (b) starch grains in latex canal of spurge, (c) resin canal in a conifer, (d) gum canals in algae

The specific odors and flavors of plants are due to the accumulations of various specially manufactured materials and certain by-products of metabolism. These substances, known as excretions, are manufactured and stored in individual cells or in long tubelike reservoirs that are formed when several secretory cells unite. They serve as reserve foods and protections against injuries, to cover up wounds and attract insects,

and for many other purposes. Many by-products that cannot be excreted by plants and would otherwise be poisonous to them are neutralized by being combined with calcium and accumulated as crystal deposits in special cells (Fig. 34). The white gummy fluids that we call latex, found in many plants, are harvested and processed into rubber (Fig. 45). Aromatic oils of all kinds are used in the perfumery and cosmetic industries. Turpentine, gums, and resins of all types, as well as thousands of other excretions, are used for a multitude of purposes by man. Some excretions are very unpleasant, and a few plants such as certain mushrooms, water hemlocks, poison oaks, and poison ivy, secrete substances poisonous to men and animals.

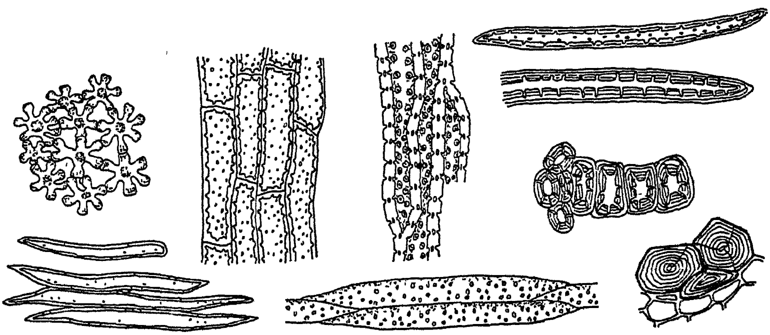


Fig. 46. Supporting cells and fibers

As a seedling grows and develops into a mature plant, some of the soft body cells gradually change into mechanical strengthening tissues by elongating and thickening at the corners. As the plant grows bigger and heavier, cellulose is added to the walls of those cells and they become very thick and pointed at the ends. As more and more cellulose is added, the cells are pressed tightly together and arrange themselves into very long strands of tissues which we call fibers (Fig. 46). Linen, hemp, jute, and other plants have fibers over ten inches long. These are extracted and processed into cloth, various kinds of baskets and other woven materials, and cords of all kinds.

After a fiber tissue has reached its full length, the cellulose of the walls may eventually be transformed into a hard woody matter called lignin. The mature lignified fibers of trees are strong enough to support the tallest and heaviest trees although the stems and trunks may be relatively thin in comparison with their great height. Moreover, these fibers are so elastic that they stretch and return to their original position when stems, trunks, and branches are swayed back and forth by heavy winds.

Some of the mechanical cells, instead of following this process, re-

main small and become so very hard and rigid that they cannot be compressed or broken unless they are softened by water or great force is used. Such structures, called stone cells (Fig. 36), are found as coverings of nuts and the pitty, gritty matter in some pears.

As long as the movements of fluids within a plant are restricted to the body cells and tissues, a plant is unable to grow very high or extend its working surface outward to any great extent. The enormous amounts of water and dissolved substances that circulate in large trees are unable to move rapidly enough through cells, even when aided by special openings in the cell walls. During evolution and the progressive change of plant structures, from the simplest seaweeds to the highly specialized land plants, conductive tissues became more and more complicated and specialized. The highest types of plant structures have magnificently efficient systems of conducting throughout their structures the enormous amount of water and dissolved substances they need.

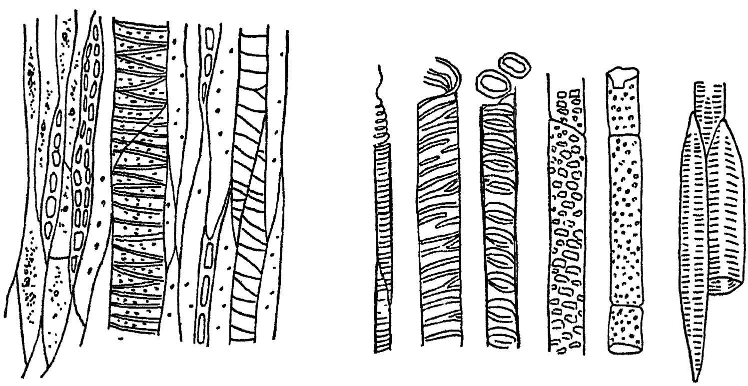


Fig. 47. Xylem—dead-wood cells that conduct water and mineral elements upward

The water and dissolved salts that are taken in by the absorbing cells of the roots pass through several body cells until they reach the inner system of upward conducting cells. These are true wood cells, and the tissue formed by them is called xylem, which is from the Greek *xylon,* meaning wood. There are several distinct types of wood cells (Fig. 47).

The elaborated foods that are manufactured in the leaves and various other processed materials are moved back and forth to places where they are needed, or for storage, through a system of living cells called sieve tubes (Fig. 48) because a series of openings in their end walls closely resemble those of a sieve. Strands of protoplasm extend from one cell to another through these openings. These sieve cells are supported and aided by specially adapted living structures called companion cells.

The sieve tubes together with their companion cells form the so-called bast or phloem strands of the plant.

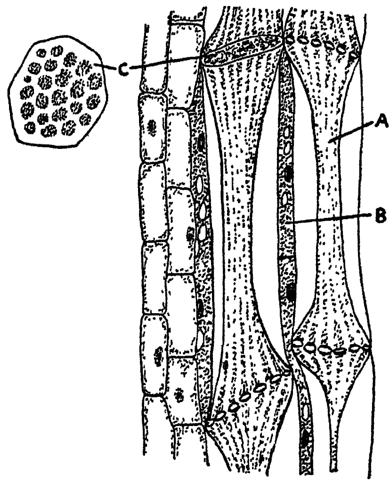


Fig. 48. Phloem—living, food-conducting sieve or bast cells: (a) phloem cell, (b) companion cell, (c) cross section of sieve

In large stems and very thick roots there is a third system of conductive tissues called the wood rays. These specially constructed wood cells facilitate the movement of materials to and fro between the outer and inner cells of those organs.

The upward conducting wood cells and the downward phloem system of woody stems and roots of trees and shrubs are arranged as continuous rings. They are separated by the cambium, which forms distinct layers of new wood and bast cells, while new shoots and leaves are being produced by the growing points. In herbs, the wood, bast, and cambium cells are united either in several separate strands that are called vascular bundles (Fig. 58) or in cylinders.

The construction, arrangement, size, and form of the various types of cells and tissues of any particular plant stand in close relation to its needs and mode of life. A large tree has larger and stronger fibers than a small shrub. A grass plant like wheat does not need the elaborate conductive system that a mature oak must have.

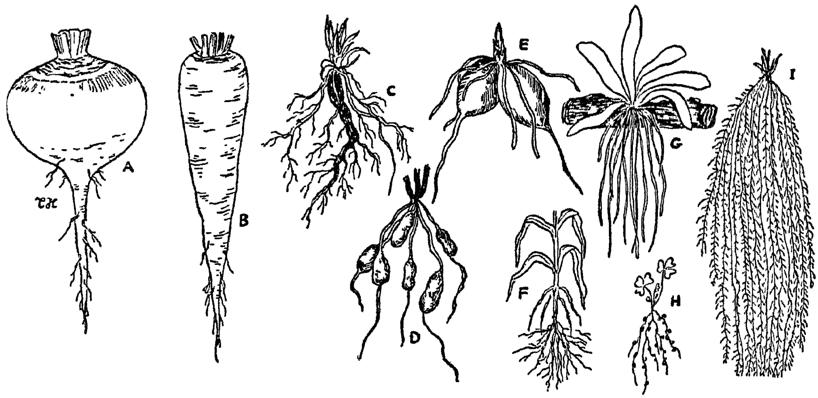


Fig. 49. Roots: (a) turnip, (b) carrot, (c) contracting tap root of dandelion, (d) bridal wreath root with tubers, (e) succulent root of an orchid, (f) adventitious prop roots of corn, (g) aerial roots of an orchid epiphyte, (h) legume with nodules that contain nitrogen-fixing bacteria, (i) part of the enormous root system of a prairie grass plant

13. A STRONG FOUNDATION

ONE of the outstanding characteristics of most water and all land plants is that they are fixed in place. Even the most primitive forms of green vegetation manufacture their own food, and as their immediate environment furnishes them with all the elements needed, they do not have to move about in search of nutrients. Most animals, on the other hand, are unable to manufacture their own food, and therefore must be able to move about in search of water and elaborated foods. During the course of evolution those plants that were able to attach themselves to some object and take advantage of a protected, well-lighted, warm spot between rocks, or in a quiet cove, were better able to survive because they were not moved away by currents and waves to cold and otherwise unfavorable localities. Some of these gradually evolved into large organisms.

The highest forms of land plants send down a very complicated system of specialized tissues that are especially adapted to the dark and damp environment of the soil. This great mass of underground parts makes up the enormous root system of a plant. The growth and development of the aboveground portion, which is called the shoot system, is directly influenced by the roots because they absorb the water, nitrogen, and various salts of the earth and convey these to the upper re-

gions. The roots of many plants are also very important for food and water storage.

The formation of the root is initiated when the seed is formed in the parent plant. Special daughter cells of the growing points are changed into elementary root structures while they are being tightly packed together at the lower end of the forming embryo. When the seed falls into a suitable location and starts to germinate, the cells in this part of the embryo begin to divide and form new daughter root cells. Various special growth-activating hormones influence these cells to grow downward into the earth. The action of the root hormones of most plants is so strong that no matter which way the seed may be turned when lying in the ground, the growth arising from the original root cells will turn so that the root will be forced downward and thus away from light.

At the very tip of the root (Fig. 50) a protective covering called the root cap is formed. This cap protects the inner delicate dividing cells from being bruised and torn apart by rough-edged rock fragments as the root is growing downward and forcing its way deeper into the soil. Usually an oily solution formed around the root cap makes the tip slimy and permits it to be pushed with greater ease between the soil particles.

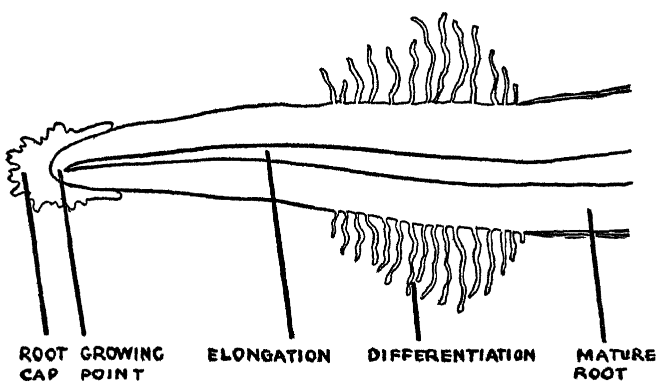


Fig. 50. Diagram of a typical root tip

The actual growing point is just behind the root cap. This is where the meristematic cells continue to divide and form new cells. Some of these are constantly being added to the protecting cap as old ones are worn off, and the others are attached to the root itself, which grows to be longer as more new cells are made and enlarged.

Those cells that are left behind as the growing point advances downward absorb great quantities of water, which stretches them. They are enormously enlarged, especially in length, and by elongating they push

the growing point farther into the soil. The root system, like any living organism, grows both by the formation and by the enlargement of new cells.

When the cells have ceased to elongate, they start to change into specialized tissues. The region of the root that is situated between the end of the elongation zone and the section where the cells are fully differentiated is a most important area in all vascular plants. It is through the outer skin cells of this region that plants take in their water and other soil nutrients. In many plants the tips of these special absorbing cells grow outwardly and form very thin long hollow tubes called root hairs (Fig. 20). Root hairs may be anywhere from a hundredth of an inch to over an inch in length, and there may be as many as 280,000 of them in every square inch of absorbing area. During a four-month growing period a rye plant that was recently studied grew a hundred million new root hairs, equivalent to fifty miles of them, daily. When this plant was taken out of the soil it had over fourteen billion root hairs, which afforded the plant an underground absorbing surface more than twenty times larger than its aboveground evaporating surface.

Although each cell in the plant body has a selective membrane that has a certain degree of control over the substances entering that particular unit, the membranes of the root absorbing cells have a marvelously exacting selectivity of all the materials that enter the plant from the soil, and thus have a certain degree of control over all the activities of the entire organism. The root hairs of a wheat plant will take in materials only in the proportions needed for that type of growth, and these will not be the same in amount and kind as those that enter an orange tree. In other words, the absorbing cells of each species possess a special selectivity for that type of vegetation.

The root hairs are covered with a sticky substance and twist themselves around the tiny soil particles so tightly that the plant is firmly anchored in place. Large trees remain upright in the face of terrific winds and storms because of the strong anchoring power of their intricate root systems. Moving sand dunes are held in place, and exposed soils—even on steep hillsides—are saved from harmful wind, water, and other weathering agents by the intricate mats that various types of grasses and other forms of vegetation produce.

As the growing point forms new cells and the root tip grows downward, new root hairs are constantly being made. Older ones farther back are dropped off as thick cork and bark coverings are laid down under the original skin cells. Thus new absorbing areas constantly appear in untapped regions of the soil. Any living plant, however old, constantly forms new absorbing surfaces and is thereby continuously supplied with water and soil elements. The absorbing cells remain alive and function anywhere from a few days to several weeks or months. Their length of

life depends upon the kind of plant, the rate of growth, and the conditions of the soil. They develop best in a well-aerated soil that has a certain amount of moisture. When the absorbing cells become old and cease to function, they increase the thickness of their outer walls by depositing layers of cellulose, wax, and other substances, which form a tough protective covering.

The various tissues within the root are arranged so as to facilitate the movement of materials, protect the vital conductive tubes and vessels, and store a certain amount of reserve food and water. The covering skin cells extend back from the end of the absorbing area and intermingle with the cork and bark of the older roots or come in direct contact with the stem. Inside the skin cells are the body cells, which make up the greatest portion of young roots and form a tissue system called the cortex. This is the main processing and food and water storage area of the root. The inner central cylinder is called the stele and is made up of the cambium dividing cells, which produce the inner woody upward-conducting vessels, and the sieve tubes or phloem, which convey food downward from the upper regions. The tubes and vessels within the central cylinder are arranged in various characteristic patterns in different plants.

As the roots of large plants increase in width, new layers of wood and phloem are added. These push the soft body cells of the cortex out and force them to break up and fall apart. In time, owing to this activity, the cortex layer of older roots is very thin, and the wood cells are increased in number and eventually may resemble woody stems. The roots of some very large trees sometimes develop a secondary cambium layer between the cortex and the skin, which forms cork and bark tissues.

When a root reaches a certain length and width, special dividing cells in the inner cambium change into new growing points and form new root tips that grow out through the cortex and skin to form secondary branch roots (Fig. 51). The root caps of these new roots manufacture special enzymes that dissolve the cell walls of the tissues through which they pass on their way out. Many other side roots may later be formed from those already developed. Eventually many branch roots may be formed, and the root system may become greatly ramified and penetrate the soil in all directions, tapping a vast area.

Some plants have shallow and wide root systems, others have deep penetrating ones. When plants are very crowded together the roots are unable to spread out to any great extent. The roots of some plants respond to changes of moisture in the soil and turn from a section of soil that has a low water content to a place where there is sufficient water. Roots are able to follow moisture in the soil only when they are either in direct contact with it or so close that water can move to them by cap-

illary action. They are unable to pass through a layer of dry soil in order to reach a supply of moisture that may be beneath. Roots cannot detect a substance needed for their growth and development and grow toward it. They can take in only those substances that their absorbing surface comes in contact with in the soil solution. When they reach a portion of soil that is rich in nutrients, they will form many side branches and an enormous number of root hairs and remain there until that supply is exhausted before continuing their downward growth.

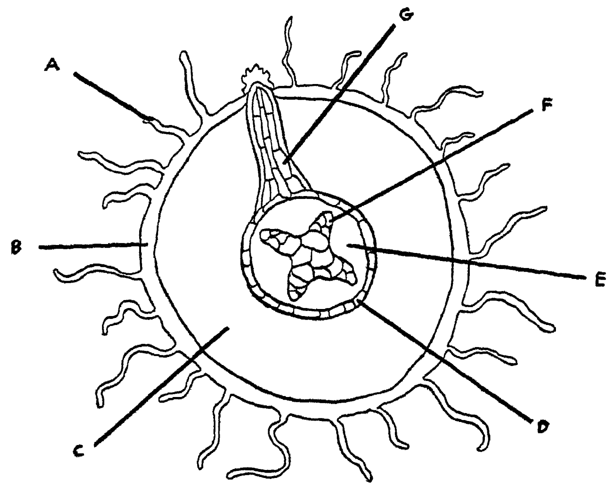


Fig. 51. Cross section of root: (a) root hairs, (b) skin cells, (c) cortex, (d) cambium, (e) central cylinder or stele, (f) conductive cells, (g) growth of secondary root

When the proper conditions for growth prevail there is apparently nothing to limit the extent of the root system except the length of the plant's life. Most root systems extend many feet in depth and cover a much greater area than the total aboveground growth. Beets, carrots, and other similar plants have root systems from five to eight feet deep. The roots of a single tomato plant will thoroughly ramify over three hundred cubic feet of soil. A single corn plant may have well over ten thousand side roots arising from twenty-five main roots. A mature wheat plant may have over sixty-seven thousand roots that can be seen with the unaided eye, and these may have a combined length of over a quarter of a mile. The rye that was recently studied had fourteen million roots, the combined length of which was 387 miles. As it is practically impossible to uncover and separate the billions of roots of large trees, we have no idea how many there are or how many hundreds or maybe thousands of miles their total length may be.

The first root that is formed from the embryo usually grows straight down and is called the taproot. The taproots of dandelion plants and oak trees are especially large and distinctive. A certain relative of the sweet-potato plant, man-of-the-earth (Ipomoea), forms huge taproots that sometimes weigh over two hundred pounds and are shaped like a human form. These plants grow in the tropics and are harvested for the large quantities of starch they contain. In many plants large quantities of food in various forms are stored in taproots and also in clusters of fleshy roots. The root crop most important to man is the sugar beet, which supplies us with a large percentage of our sugar. Arrowroots and cassavas, from which tapioca is manufactured, sweet potatoes, and yams produce fleshy roots that are very rich in carbohydrates and are the chief source of food for large populations in many parts of the world. Other important root crops are stock and garden beets, carrots, horseradish, turnips, and parsnips. Many drugs are extracted from a wide variety of roots, especially from licorice, sarsaparilla, mandrake, ginseng, rhubarb, valerian, and monkshood plants. Certain poisons are extracted from the roots of the pyrethrum, which is a daisylike plant, and the poison rotenone is taken from a member of the pea family. These poisons are used to combat harmful insects and other pests. The roots of Russian dandelion plants are very rich in latex and may become important new sources for rubber (Fig. 45). The brierwood that is used in pipes comes from the roots of erica plants.

In plants such as certain mosses, primrose, mangrove, grasses, corn, and many palms the original embryonic root dies soon after the seedling is well formed. The new roots that arise from the stem and all other roots that do not originate in the embryo are called adventitious roots. They may arise anywhere in the plant where there is a layer of active dividing cells in the form of growing points, buds, cambium tissues, or special cells that have regained their dividing power. The stems of figs, roses, blackberries, willows, and many other plants develop roots very easily when placed in damp soils. Roots arise from the underground stems of asparagus, banana, potato, grass, and bulbous plants with great facility. The leaves of many ferns, begonias, and other plants are able to produce roots when placed in proper environments. The dividing cells of the roots of some plants such as sweet potatoes, yams, dahlias, roses, and red raspberries have the power to form stems and leaves under certain conditions.

When adventitious roots arise above the ground they must pass some distance in the air before coming in contact with the soil. Such supporting or prop roots are very common in corn and screw pine (Pandanus) plants (Fig. 49-F). These do not have far to travel before coming in contact with the soil. There is a certain tree growing in India called the banyan tree (Fig. 52) that is related to our common figs. This tree

starts life as a seed that is deposited by birds on branches and in crotches of date palms. When the seed germinates it sends its roots down to the soil, where they twine around, embrace, and kill the original supporting palm tree. When the first supporting root attains a certain thickness the young plant sends out side branches in all directions, and each branch in turn forms adventitious roots that descend as long slen-

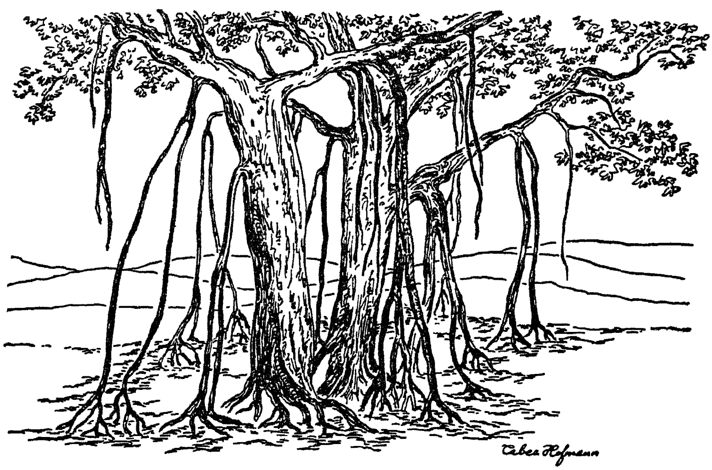


Fig. 52. Banyan tree (*Ficus bengalensis*)

der shoots to the ground, where they root. When they have rooted they increase in size, and in time hundreds of columns are formed extending outward from the original parent stem. One famous banyan tree in India has three hundred large and over three thousand smaller stems, and forms a huge grove many hundreds of feet in diameter. The common vanilla vine, whose beans we use in ice cream, puddings, cakes, and other foods, grows on high living trees or poles. It sends down one main large root that grows in the soil and many smaller aerial roots that gather additional moisture from the damp atmosphere in the tropical rain forests where it lives.

The roots of many aerial plants never reach the ground (Fig. 49-G). These attached green plants that manufacture their own food are called epiphytes. Birds, insects, and winds deposit the seeds of these plants on the trunks of trees, where they develop their own growth; they use the plant they are attached to only for support. These plants form delicate hairlike growths that act like sponges and absorb the needed moisture and nutrients from the surrounding air. Most orchids, many mosses, lichens, liverworts, club mosses, ferns, and a great variety of other types of vegetation growing in tropical rain forests are epiphytes. Some vascu-

lar epiphytes that are commonly found in the United States are Florida moss and air pines. Some orchids are leafless and depend entirely on their aerial roots for nourishment; hence these structures perform all the functions of stems, leaves, and roots.

Many plants use their roots in a number of ways. Mangroves and some other trees that grow in marshes and other wet places send up large roots that look like knees. These outgrowths have openings that permit the exchange of gases between the underwater roots and the upper atmosphere. Plants that have bulbous stems such as dandelions and violets grow close to the ground and have roots that shrink and become smaller in the wintertime. By contracting they pull down the bulb or crown that has the delicate growing point and bury it in the ground for better protection against frosts. Climbing stems of such plants as English ivy, trumpet creeper, and poison ivy have large numbers of tiny roots that are formed on the side of the stem facing the support. Some seed-bearing plants live as complete or partial parasites on others. These have special absorbing structures called haustoria, which are able to penetrate into the host that supports them. The mistletoe manufactures part of its own food, usually drawing only water from its host, while the dodder and rafflesia have no leaves and rob and kill their hosts. The Spanish moss and several other aerial plants have no roots at all. The stems and leaves of those plants perform the work that roots usually assume.

The roots and stems of some plants are spotted with enlargements that are caused by irritations due to the presence of bacteria, certain fungus growths, and insects. Some of these are very small and are called nodules or tubercles. Those present on the roots of the members of the pea family are due to the very beneficial nitrifying bacteria. Some enlargements are called galls and are very harmful. Violets have almost invisible galls, on roses they may be as large as ducks' eggs, and the galls on some forest trees may be over ten inches in diameter. The galls of many plants are rich in tannins, which are used widely in the leather industry.

The roots of many plants form associations with certain fungus growths for their common benefit. The fungus growth produces certain enzymes that process various nonavailable materials and convert them into a soluble form that the land plant is able to absorb and use. In turn the roots of the host supply the fungi with certain nutrients they need. Many orchids and some forest and orchard trees are unable to thrive without their fungus root partners. Such beneficial fungus partners are called mycorrhiza.

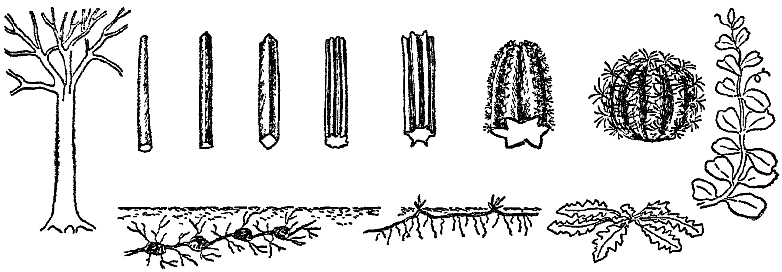


Fig. 53. Erect, reclining, and underground stems

14. SUPPORTS ARE ESSENTIAL

THE aboveground portion of most higher forms of land plants is composed of the shoot system, which is made up of leaves, stems, and branches, and the reproductive organs, which produce the spores and seeds. The chief functions of the stems and branches are the conduction of fluids and various materials in solution; the production, support, and exposure of the leaves and reproductive structures; and the storage of foodstuffs and water. Stems form the conspicuous feature of many plants, and in woody species they constitute the largest portion of the plant body. Stems may be thick or thin, self-supporting or climbing, erect or trailing, hard or soft, above or below the ground, depending upon the role of each kind of plant in the vast vegetable population that covers the earth.

The shoot system originates in the embryo of the seed in the same manner that a root does. But unlike the roots, which grow downward away from light into the ground, the growing points of most stems grow upward. Those groups of cells that are destined to become branches, leaves, and reproductive organs are differentiated in the growing point before they start to elongate, and are usually assembled with special dividing cells in small associations called buds.

The first cells that have been changed into leaf structures grow faster than the others. They curve upward over the growing point and specialized structures to form a protective covering. The original growing point, the miniature shoot, and the protective rudimentary leaves together form the terminal bud of the plant.

The new daughter cells formed by the activity of the growing point are attached to the original stem. Those daughter cells that will eventually grow and develop into side branches, leaves, and reproductive

organs are folded, bent, twisted, and overlapped in exacting order and precision, each kind of plant forming its distinctive inner bud structure and outer coverings (Fig. 54). In annual herbs and many tropical plants, the terminal and lateral buds are covered only by the rudimentary leaves and are called naked buds. In most perennial herbs and woody plants, the delicate structures have scales covered with gummy, resinous, waxy, and hairy substances that afford added protection against excess water loss, injury, and disease and insect attack. The number of covering leaves and scales varies in different kinds of plants. Willows and sycamores have a single enveloping scale that is ruptured when growth commences in the spring. Tulip trees and dogwoods have two scales, maples have four, and elm trees have six or eight. Some buds, especially the terminal buds of many trees, are large and distinctive. The flower buds of magnolia trees are pear-shaped and over an inch in length. Many buds are very small and inconspicuous; some are hidden by leaves and skin cells. Some plants such as dates have a single bud only. A mature full-grown elm may have over seven million buds. In some plants, flower structures and shoot systems are placed in separate flower and shoot buds; in others both the reproductive and stem structures are present within the same or mixed bud.

Leaves and buds are not attached haphazardly along the length of the stem, but are placed in definite joints or nodes (Figs. 54, 63). Nodes are characteristic features of all stems. They are very large and distinctive in bamboo, corn, and other grass plants. When woody twigs age and are covered with cork and bark tissues, the nodes are hidden from view. Dividing cells that may remain dormant but retain their dividing power indefinitely are deposited together with the buds and leaves in the nodes as they are being formed. Adventitious roots, stems, leaves, and even flowers may later develop from these unspecialized cells when a plant is heavily cut or otherwise injured. Every vascular bundle and other conductive tissue eventually terminates at a node, where it comes in direct contact with the organ it serves. The lowest node on the plant, which forms the junction between the stem and the root systems, is called the collar. As a general rule the cells that form the structural framework of the nodes do not grow or elongate the stem to any great extent. However, the cells on the undersurface of the nodes of some grass plants can grow and elongate when those stems have been bent down by heavy winds or snows. By growing they return the stem to its original erect position.

The sections of the stem between the nodes are called internodes (Fig. 54-J). The length of the stem depends, to a great degree, upon the elongation powers of the cells in the internodal regions. When those cells do not enlarge very much the stem remains small and has a stunted appearance, as in dandelions, violets, cabbage, most cacti, and many

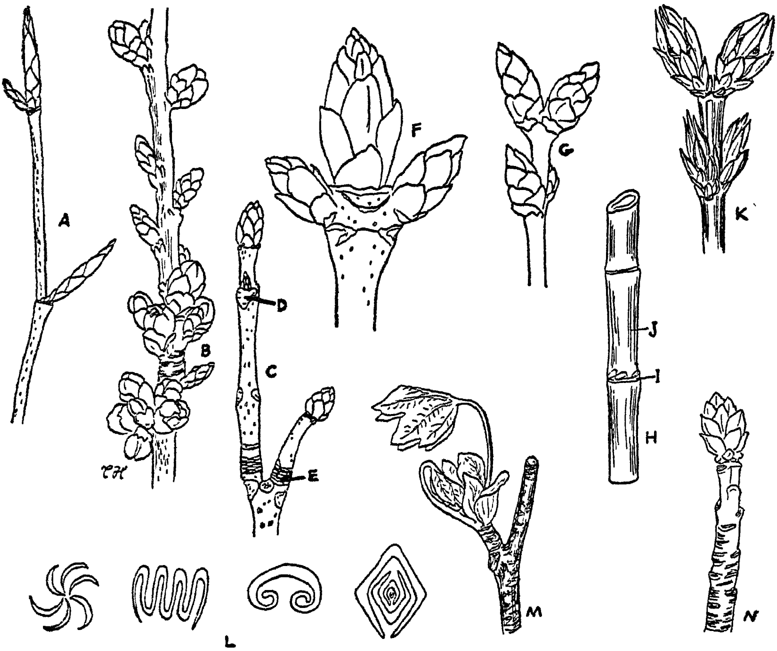


Fig. 54. Buds: (a) twig of beech, (b) budding cherry branch, (c) horse chestnut, (d) leaf scar, (e) bud scars, (f) eating chestnut, (g) lilac, (h) bamboo, (i) node with axillary buds, (j) internode, (k) syringia, (l) arrangements of miniature shoot systems in buds, (m) expanding bud of tulip tree, (n) terminal bud of hawthorn

weeds. When the cells elongate enormously—some may enlarge themselves eight thousand or more times—they may increase the distance between nodes to two feet or more.

The cells of the internodes may continue to elongate for a relatively long period of time—several weeks—and the elongation section may extend down through several internodes for a distance of five inches or more. Usually growth takes place at night, and is so slow that it can be detected only by very careful measurement. A healthy plant that has the inherited ability and experiences a perfect balance of environmental conditions may grow rapidly. Some grasses, especially bamboos, may grow as much as two feet in a twenty-four-hour period when enjoying optimum environmental conditions. Once the cells have reached maturity they cease to elongate; the distance from the collar node then remains the same as long as the plant is alive and intact. Marks made on a fully developed mature tree will remain the same distance from the ground, even after the passage of many years.

The formation of successive nodes and internodes by the activity of the growing points is continuous in annuals, and in many herbs and woody plants that grow in warm moist tropics. Many evergreen perennial plants that grow in favorable localities experience several alternating growing and dormant periods annually. Some citrus trees undergo as many as five growing and resting cycles every year. The growing points of woody exposed twigs and those of the fleshy underground stems of perennial plants living in cold temperate and arctic zones grow rapidly during the warm moist spring and early summer months. They stop activity in late summer by forming dormant well-covered buds, which protect the dividing cells during cold autumn and winter months, or during periods of severe drought.

Palm trees and some herbs do not form any lateral shoot buds. During their entire lifetime such plants have only one exposed growing point, and are able to produce just a single unbranched stem. Plants with a terminal growing point that has the ability to form lateral shoot buds are able to extend their working surface by having branches. Pines, spruces, and other plants that have a single main stem with several smaller side branches exhibit a pyramid or conelike shape. Their lateral buds form secondary growths that are smaller and weaker than the growth produced by the main terminal bud. In this type of growth the original growing point dominates all the other buds and produces the greatest amount of growth. Those plants that have rounded tops have lateral buds with as much strength and growing ability as the terminal growing point. A bushy type of growth is formed when several axillary buds that have equal powers arise near the collar node of the plant, and the terminal growing point loses its dominating force.

The form of branching is determined largely by the growing ability of the lateral buds, and their number and position in the nodes (Fig. 55). Many lateral buds remain dormant throughout the life of the plant. Others may start to develop in later years and form adventitious branches because of some injury to the shoot system or other stimulating factor. Usually only a very few of the lateral buds that are formed ever develop into branches. Therefore, branches may not be regularly arranged. When trees grow to be very tall, or when they are growing closely together, the lower branches and leaves are hidden from the sunlight and die out. They fall down and leave a straight unbranched trunk that may be many feet high. As the trunk grows in thickness, the stubs of these fallen branches are covered by new wood and form knots that spoil the quality of wood. When there is a single bud at a node, as in most plants, the branches will be arranged in an alternate or spiral fashion around the stem. When there are two buds, as in maple trees, they will be exactly opposite each other. When several buds are bunched to-

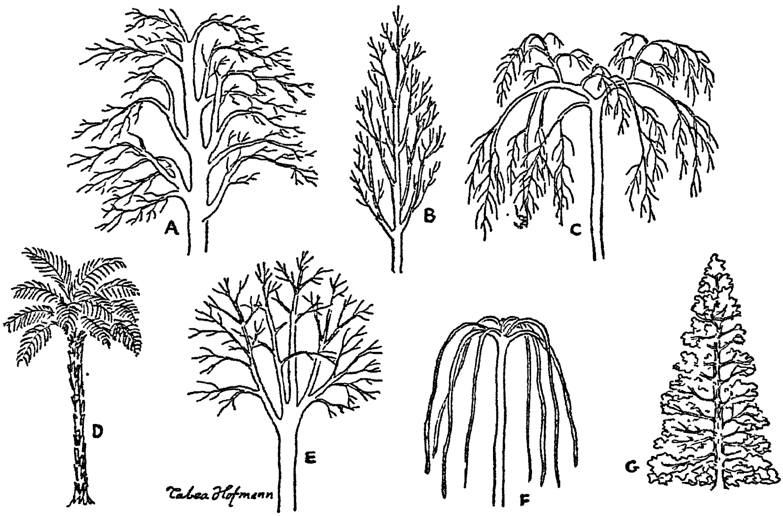


Fig. 55. Branching: (a) cedar, (b) poplar, (c) ash, (d) palm, (e) maple, (f) Japanese saphora, (g) conifer

gether in a node, as in chara and horsetail plants, a whorled branching effect will result.

We are able to distinguish many different kinds of woody plants in the wintertime by their form, their bark, and the various markings that are displayed on the surface of their twigs (Fig. 54). Each kind of plant has its distinctive type of bud structure. The scar left on a twig after a leaf has fallen may be triangular, circular, or moon-shaped. The ends of the vascular bundles within the leaf scars are seen as tiny raised points. Their number and arrangement are different in every kind of plant. At the beginning of each growing season the covering scales of the terminal buds fall off, leaving traces in the form of complete thin circles. Since new terminal buds formed at the end of a growing season in the fall remain dormant through the winter, and the growing point starts activity again in the spring, a bud scar is left behind each year. We can tell the age of twigs on bushes and trees that experience a single growing and resting cycle each year by counting the number of bud scars. We can also tell the amount of growth made each season by measuring the distance between the scars. We are seldom able to tell the age of the entire plant by this means because the older stems are usually covered with cork and bark, which hide the markings. When the smooth tight covering of young bark is unable to expand or stretch, rough outer bark is formed. As succeeding layers of new wood are added within the stem, they push against the thick bark coverings, which are broken apart into

smaller uneven sections. Each kind of tree has its own way of breaking its bark, and this forms the characteristic patterns by which different species are identified.

Woody Stems

During elongation the newly formed cells in the internode sections of the stem start to change and develop into specialized tissues. All the structures formed from the cells that have been laid down by the growing points are called primary tissues. These include the outer protective skin tissues with their manufacturing cells, coverings, hairs, glands, and stomata; the inner body cells, which make up the cortex, where the main storage and processing activities take place; thin strands of dividing cells, which will later be changed into cambium; the original central cylinder, which is made up of the first conductive tissues; and the innermost soft pith cells, which resemble the body tissues of the cortex.

All the cells formed within the stem after the primary tissues have matured are called secondary tissues. These are formed by the inner and outer cambium layers. The inner cambium dividing cells produce the upward-conveying and strengthening wood cells, the downward-conductive phloem tissues, bast fibers, and wood rays. The outer cambium forms the outer protective cork and bark tissues.

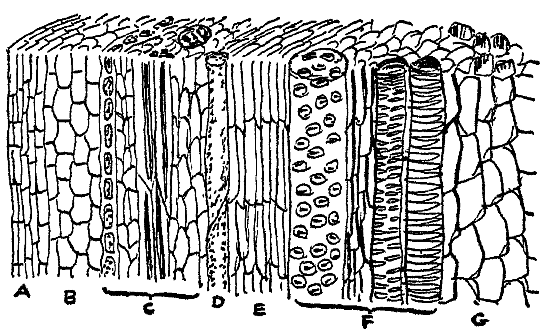


Fig. 56. Enlarged section of woody stem: (a) epidermis, (b) cortex, (c) fibers, (d) phloem, (e) cambium, (f) xylem wood cells, (g) pith

Wood is formed as cambium cells divide themselves lengthwise (Fig. 56). The inner daughter cell, after the division of a cambium cell, changes into a wood cell, and the outer daughter cell retains its dividing power. When this active cell again divides itself, again the inner one will be wood and the outer one will remain active. Occasionally when a cambium cell divides, the inner one retains its dividing power and the outer daughter cell is changed into a phloem cell. These processes are

repeated time and time again during the growing season. Thus by division of the cambium cells a relatively large amount of wood is added to the outside of the older wood, and a small amount of phloem is added to the inside of the previously formed phloem. Woody stems result when the wood cells form a connected tissue that completely surrounds the inner pith. As there is a striking difference between the large cells that are formed during warm damp seasons and the smaller tightly fitting wood cells that are made when growth slows down, the wooden parts of stems show a series of rings.

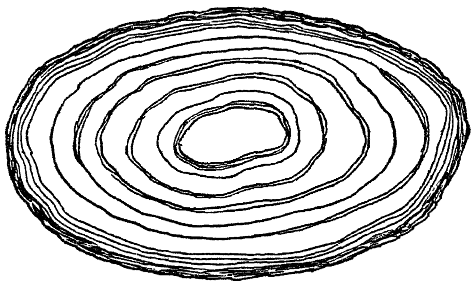


Fig. 57. Cross section of woody stem showing seasonal rings

As woody plants in temperate zones experience one alternating cycle of growth and rest each year, their age may be learned by counting the rings when the trees are cut down, or when small sections of wood extending from the outside bark to the inner central pith are extracted (Fig. 57). By studying the different shapes, sizes, and other features of these rings, we can tell a great deal about the former life of the plant. The rings are narrow when growth is retarded by drought, shading, crowding, or cold spells. They are large when the plant enjoys sufficient space, rain, and sunshine. Scientists study carefully markings left by storms, fires, lightning, and other events. In favorable regions rings in growing trees and those found in beams from ancient ruins and buried logs have been compared, and from the data secured calendars dating back many thousands of years have been made. Rings in trees that were cut down and used in building shelters and other structures thousands of years ago give us the exact building dates of those ruins. By these means many ancient civilizations of the New World have been dated as definitely as those civilizations in the Old World that have left records on old stones. It is, of course, impossible to tell the age of trees that experience several growth and resting periods annually, because there is no way of telling how many alternating growth and dormant periods were experienced in any single year.

The formation of new layers of wood cells may continue indefinitely in trees that have strong supporting tissues and very efficient protective coverings. The stems of small vascular plants may be only a few cells in thickness, and they may live just one season. Some trees such as the eucalyptus, chestnut, oak, olive, and especially the giant redwood may grow to be many hundreds, even thousands, of years old, and have stems that are thirty or more feet in diameter.

New wood and phloem cells formed each year provide passage for the required nutrients to the current season's roots, twigs, leaves, and reproductive organs. As only the recently formed sapwood that lies right next to the cambium is used for the conduction of materials, the inner or heartwood is inactivated and serves only as a supporting structure. Sometimes the inner heartwood is decayed and completely disappears, leaving a thin shell of living tissue around a hollow trunk. As long as there is a continuous layer of living cambium and active conductive tissues that connect the roots to the twigs and leaves, even though the amount be very thin and small, a tree may continue to live for many years.

Herbs

Nonwoody plants are called herbs. Usually their outer protective tissues continue to retain their manufacturing cells and remain green dur-

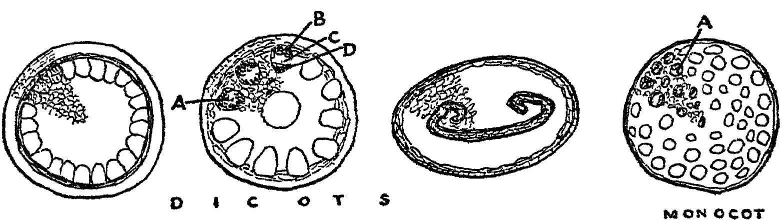


Fig. 58. Cross sections of herbaceous stems: (a) vascular bundles, (b) phloem, (c) cambium, (d) xylem wood cells

ing the entire life of the plant. These plants do not form continuous layers of thick wood. Their inner structure is composed mainly of soft body cells. In the stems of such plants as alfalfa, sunflower, and bean the cambium tissues, woody cells, and phloem strands are arranged in regular distinctive patterns, or as a single small continuous circle (Fig. 58). The stems of grains, bamboo, corn, and other similar plants have many vascular bundles that are scattered within the soft body cells. The inner pith tissues of some of these plants disappear and form hollow stems.

Those herbaceous plants that grow in temperate and cold climates and

are unable to store sufficient food and protect their growing points are killed by fall frosts. Some herbs such as chrysanthemums and geraniums, which are annuals in cold or dry regions, may live several years in suitable warm and moist localities. Many herbaceous plants withstand the rigors of frost and drought by storing sufficient quantities of food, protecting their growing points, and remaining dormant during unfavorable climatic conditions. Gladiolus, crocus, and jack-in-the-pulpit plants protect their growing points underground and form large fleshy stems around their growing points (Fig. 59). Onions, tulips, and lilies have many layers of leaves that cover the delicate inner growing points. Asparagus, bananas, dandelions, rhubarb, violets, and many weeds have more or less stationary underground stems that form new buds every year, which grow into exposed fruiting shoots. After the seeds have ripened, the aboveground portion dies in the fall, and the undersurface stem forms new buds and growth the following year. Such plants may live for many years.

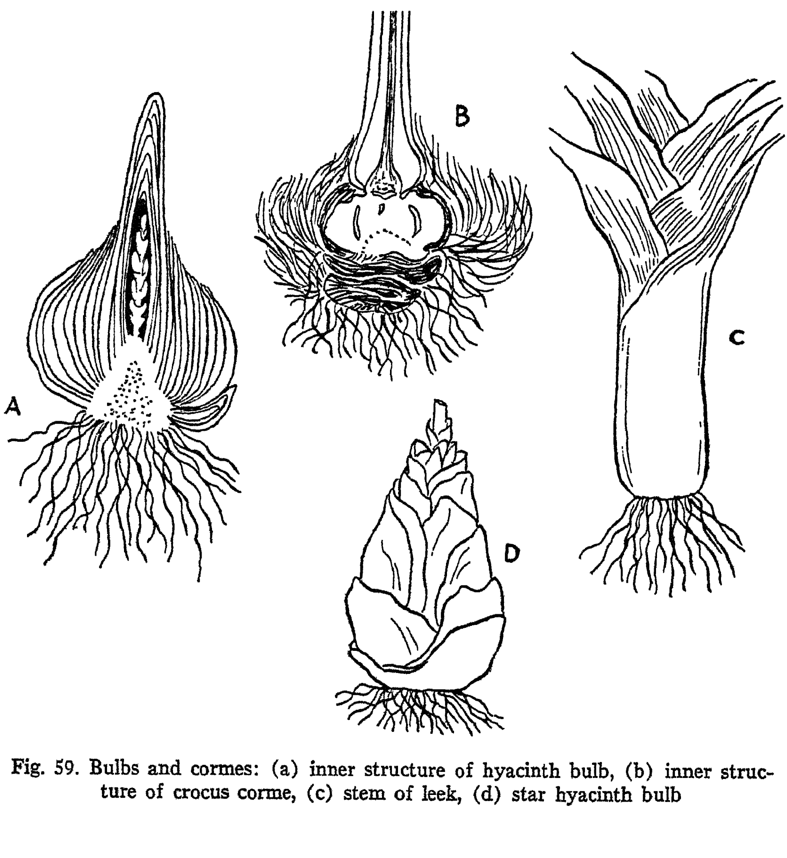


Fig. 59. Bulbs and cormes: (a) inner structure of hyacinth bulb, (b) inner structure of crocus corme, (c) stem of leek, (d) star hyacinth bulb

Although this succession of active growth and dormancy may sometimes continue indefinitely, most cultivated herbaceous perennials become weakened and are replaced after producing several crops. Alfalfa, artichokes, certain grasses, clovers, raspberries, and many bulbous flowering plants usually last from three to seven years only. Asparagus, peony, and rhubarb plants may remain productive for fifteen years when properly cultivated, and some banana plantations are fruitful for thirty or more years.

Fig. 60. Underground stems: (a) potato tubers, (b) rhizome of Solomon's-seal

The growing points of some herbaceous perennials like dandelion and dahlia are placed on top of the storage organ, which remains fixed in place, and the exposed flowering stems reappear in the same place every year. Others have so-called creeping stems, because their growing points form new permanent vegetative growth and nodes each season (Fig. 60-B). Some, like Solomon's-seal, have only one growing point at the end of their single stem, and form a single new node yearly. Rootstocks or rhizomes are creeping surface or underground stems of such plants as iris, ferns, and many grasses. They have many growing points that remain flat with the surface of the earth or underground and form horizontal growths. New nodes are formed every year, and from these new foliage and flower-bearing stalks arise and are exposed to the light. The older nodes, some distance away, act as storage places for a certain length of time, and then die. Such plants are practically immortal, and when growing in suitable places may live for many hundreds of years. The underground stems of potato plants form large tubers that contain important starch reserves (Fig. 60). Potatoes have several buds or "eyes."

Plants do not die of old age as most animals do. They usually die because of their inability to store sufficient food, because they are killed by some unfavorable environmental factor such as frost, drought, wind, lightning, fire, human, animal, or insect or disease attack, or because their growing points are injured or killed by some factor. When a plant has the inherited ability to set aside a store of sufficient food and water, when its supporting structure, absorbing tissues, and protective coverings are intact, and when its growing points are uninjured, it may form new cells indefinitely and lengthen its stem to enormous distances. Many trees and vines extend over a hundred feet above the ground and many times that length underground. The uppermost twigs and leaves of the giant redwood trees in California are more than three hundred feet above their root systems. The climbing long stems of many tropical vines are well over half a mile in length.

Climbing Stems

In the struggle for light and space a group of plants that we call climbers or lianas has emerged. These do not have strong supporting tissues, and are therefore unable to have erect stems. They conserve structural material by relying on some outside support such as trees, walls, poles, and rocks, or merely trail along the ground. Those that do not have any special structural modifications simply lean or clamber over other plants and supports. They are the true lianas, among which are the begonias, bauhinias, and cissus. Some resemble wavy ribbons, others are twisted into large spirals. They hang in festoons and wind among trees, leaping from one tree to another, and entangle themselves together into such huge masses that they render many parts of damp tropical jungles almost impenetrable.

Clinging vinelike plants have special structures and modifications that enable them to cling tightly to a support. The English and poison ivies use aerial adventitious roots. Roses and brambles such as blackberries use thorns and hooks. Peas, grapevines, and some other plants have small stem adaptations called tendrils, which attach themselves to and twine around a support (Fig. 61).

As a stem grows, the tip and the uppermost three or four internodes spiral very slowly and form complicated curves in space. Those plants such as bean, hop, and honeysuckle that twine around a support form spiral curves more rapidly than ordinary plants. They twist around in the air until they contact a support and then twine themselves around it. If a seedling does not meet a support soon after it germinates, it twists about on the ground until it reaches one. Most plants turn from left to right or clockwise. Hop and honeysuckle plants twist from right to left or counterclockwise.

Mosses, ferns, white clover, and members of the cucumber family are

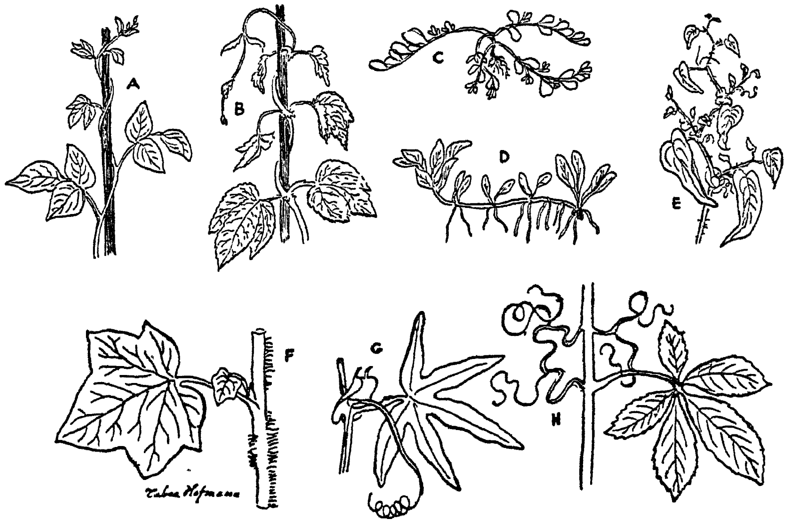


Fig. 61. Direction of growth and supports: (a) bean, (b) hop, (c) purslane, (d) bugle weed, (e) smilax, (f) English ivy, (g) passion flower, (h) possum grape

among the plants whose stems creep along the ground, and form adventitious roots at their nodes. As older parts die out, the new growths become separate independent individuals. Strawberry, blackberry, and the mother-of-thousands plants form traveling stems called stolons. These stem outgrowths produce tiny plants at their tips. When the young plants have rooted at some distance from the mother plant, the stolon withers away and the young plant is able to fend for itself. When stems arise from roots they are called suckers. These may appear several feet away from the parent plant, as in the sumac plants.

The stems of many plants are of considerable economic importance. Wood is used as railroad ties and poles, and in the building of structures, furniture, and crates. It is also an important fuel. Many products such as charcoal, plastics of all kinds, paper, alcohols, plywoods, rayon, tar, oil, and gas are manufactured from wood. Fibers are extracted from the stems of a great many different kinds of plants, including the valuable linen fibers, which come from flax plants. Tannins for the processing of leather are taken from the barks of many trees, as well as cork from cork oaks. Potato and taro are the most important starch-producing stems. Some other edible stems are leek, chive, celery, and asparagus. The most important food that is extracted from stems is sugar, from sugar-cane plants. A certain amount of sugar and syrup is

manufactured from the sap of sugar maple trees. Other important products that come from the saps of stems are rubber from the latex of Hevea or Pará rubber trees, turpentine from the resin of conifers, gum arabic from acacia trees, and lacquer from lacquer trees. There are several kinds of trees growing in Latin America that produce a white milky latex that is used as a substitute for milk, and these are appropriately called cow trees. Some of the most important spices and drugs that are extracted from stems include such important items as balsam, quinine, cinnamon, and camphor.

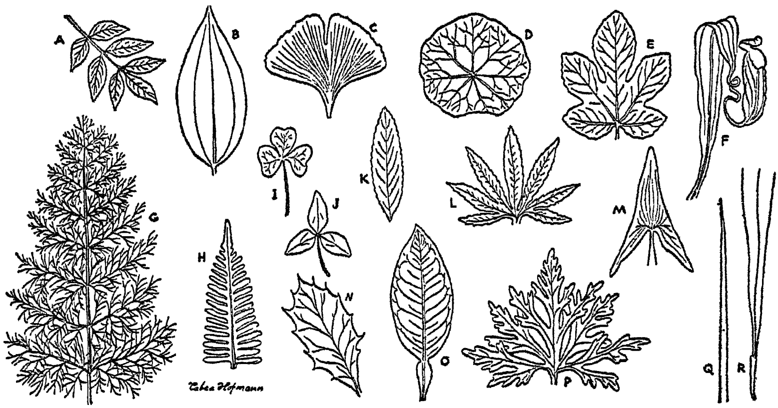


Fig. 62. Leaves: (a) hickory, (b) blakea, (c) ginkgo, (d) nasturtium, (e) fig, (f) Nepenthes, (g) dill, (h) fern, (i) anemone, (j) clover, (k) salvia, (l) hellebore, (m) arrowhead, (n) holly, (o) grapefruit, (p) coral plant, (q) flowering rush, (r) pine

15. BUSY FACTORIES

THE most distinctive and by far the most important feature of green plants is their remarkable and unique chlorophyll bodies. These alone, of all the substances in the world, are able to transform inorganic elements into energy-holding organic foods. During long geological periods through the process of evolution plants have become so adapted in their structure and growth habits as to bring their chlorophyll-bearing plastids into the most advantageous relationship with light—the source of energy. Although many plants have their chlorophyll in stems and fruits, and some have theirs in exposed aerial roots, the most efficient food-manufacturing organs are the leaves of vascular plants.

The cells that are destined to become leaves are left behind in the nodes by the dividing cells of the growing points on stems. When the growing point is active the leaf structures unfold and enlarge as soon as they are formed. In most perennial Temperate Zone plants the growing point forms the leaves for the following season during the late summer and early fall months. The entire miniature shoot system is rolled up and folded within the bud as it is being made. When proper conditions are again present, growth is resumed and the tiny stem and leaves unfold and expand. As the cells absorb water and enlarge they press the covering scales apart and open out in the exposed atmosphere. The cells increase in size many hundreds of times very rapidly, and the leaf

reaches its full size and maturity anywhere within a few days to several weeks.

Although most stems have growing points that are capable of forming new cells and growth indefinitely, only a few kinds of plants can form new cells in leaves. Many grasses have growing points at the bases of their leaves, which are able to form new leaf cells for varying periods of time. Animals may graze these grasses, or men may cut them, several times during their growth periods without harm to the plants. Only after grasses made their appearance on earth could grazing animals such as cattle, horses, sheep, and goats evolve and multiply.

After growing points stop functioning, any further increase of the leaf surface is due solely to expansion of the existing cells. The only seed plant known to have an unlimited leaf growth is the curious Welwitschia plant of Africa (Fig. 153). This unique species develops only two leaves, which continue to grow from their base during the entire life of the plant, which may extend over a period of a hundred years or more. Although the growth of the leaves is continuous, the leaves remain about the same size because the older tissues at the tips wither away and die as new leaf cells are formed and grow out from the node. Some ferns have growing points at the tips of their stems that have unlimited growing power. The leaves of such plants may reach lengths of a hundred feet or more.

The leaves are arranged around the stem in such a way that they do not shade one another but make the fullest possible use of sunlight. (Fig. 63). Their distribution around the stem is not haphazard but remarkably exact and rigorously fixed by nature. When there are several leaves at a node as in catalpa, horsetail, and oleander plants, they form a whorl. When the whorl is close to the ground as in dandelions, and many root and vegetable crops, the leaves form a rosette. The nodes of the nettle, ash, and maple plants are spaced widely apart. Each node in these kinds of plants has two leaves placed directly opposite each other. The leaves in one node are exactly at right angles to those of the node above and below.

In most plants there is just one leaf at a node, and the leaves are arranged in an ascending spiral around the stem. If we were to wind a thread around the stem, starting at any leaf and continuing upward until we reached the leaf directly above it, we should notice that an ideal spiral has been formed. This spiral, connecting two leaves that are in line, is called a cycle. It may consist of one or more revolutions encircling the stem, and pass two or more intervening leaves that are arranged at regular angles and at different heights around the stem. No matter how many revolutions are needed to complete a cycle, or how many leaves there may be between any two that are directly in line, the

number of turns and leaves is always exactly the same in each kind of plant. In some cases all the members of an entire family of plants have the same leaf arrangement. In elm and lime trees, two leaves constitute a cycle. Three leaves and a single revolution around the stem complete a cycle in the sedge, elder, and tulip plants. In the cherry, peach, plum, and a great many other plants the cycle embraces five leaves, and the spiral goes twice around the stem. The arrangement of the leaves around the stem is so mathematically exact that when we look down the stem of an elm we see two rows of leaves; elder shoots have three rows, and there are five rows of leaves in peaches and their

Fig. 63. Phyllotoxy: arrangements of leaves on stems

relatives. Another very remarkable feature about the geometrical arrangement of the leaves around the stem is the fact that the numbers of leaves and revolutions progress in a mathematical order. When there are two or three leaves in a cycle there will be just one revolution, five leaves will make two turns around the stem, eight leaves will be arranged in three revolutions, thirteen leaves in five, twenty-one leaves in eight turns, and so on indefinitely. The scales around pine cones and pineapple fruits, the tiny separate flowers in a sunflower head, and the leaf segments in an artichoke bud are likewise arranged in exact order.

Nothing in nature is more varied than the many forms that different leaves exhibit (Fig. 62). The leaves and their parts as well as all the modifications they assume are so distinctive in different kinds of plants

that they are used in describing many species. In some species, however, the many shapes and sizes are due to various growing habits and environmental factors, especially light and water relations. The saying that "no two blades of grass are alike" is very true. Leaves growing in the shade are usually thicker and their edges are more uniform than those exposed to direct sunlight, even when growing on the same plant. The leaves of sassafras and mulberry bushes are strikingly different even when growing from the same twig. In the garden valerian plants, the lower leaves are entire, while the upper ones are deeply notched. When the common arrowhead plant grows in brooks its submerged leaves form long ribbonlike growths, and when this plant grows along the banks of ponds the leaves resemble arrowheads.

In many plants various growths, called stipules, develop from the nodes at the base of the leaves (Fig. 64). These may be very small as in rose, hop, and buckwheat plants, or large and leaflike, as in Japanese quince trees, when they may function as important food-manufacturing structures. Stipules protect young buds in beech trees, are transformed into spines in locust trees, form glands in cherry trees, are changed into

Fig. 64. Stipules: (a) pea, (b) barberry, (c) buckwheat, (d) rose, (e) sensitive mimosa in natural position in daylight, (f) same after being touched, or at night

tendrils in smilax plants, and are fleshy and used for food storage in some ferns.

Although some leaves, like those of pimpernel plants, are directly attached to the stem and are called sessile, the leaves of most plants are attached by a short stalk or petiole that grows from the node and connects the widened blade to the stem. Petioles contain one or more conductive vessels that are supported and protected by layers of strong supporting cells and a covering layer of skin cells. They may remain very small and be flattened out at their ends into tiny leaflike scales as in asparagus and cypress plants, change into spines as in cacti, or become long and slender and be transformed into supporting tendrils as in pea, vetch, and nasturtium plants. The lower part of the petiole may be swollen as in mimosa bushes, or be in the form of wings as in lemon trees. The petioles of rhubarb and celery leaves are used as foods. The base of the leaf may grow over the node and even cover part of the stem to form a supporting and protective sheath. Sheaths may be entire as in sedges, or split as in many grass plants.

In many plants the petioles react to light and turn the leaves toward the best illumination. The movements of leaves toward light and away from winds and other disturbing events are sometimes performed by special localized swellings in the petioles. These special cushions work like hinges and are present in many members of the pea family. They are activated by the entrance and exit of water, and are influenced by changes in light, temperature, and humidity. Some leaves, like those of clover and certain water ferns, fold up at night and open in the daytime. The sensitive mimosa plant has leaves that are so responsive to touch, heat, and other stimuli that they fold downward rapidly when disturbed, and regain their rigidity slowly after the lapse of several minutes (Fig. 64).

The large flattened portion of the leaf is called a blade. Leaf blades are usually wide and flat and lie horizontally. The leaves of many grasses, iris, lily, and other plants that live in crowded communities stand upright and thereby avoid shadowing neighboring leaves. The sizes of leaves vary greatly in different kinds of plants. They are tiny scales one cell in thickness in the moss, fifteen or more feet in length in banana plants and date palms, and over one hundred feet long in certain tropical evergreen ferns. The huge round flat leaves of certain gigantic water lilies are over ten feet in diameter and are strong enough to support the weight of a young person. Leaves vary in shape from long slender needlelike growths of pine trees through every conceivable kind of gradation in form to round structures in nasturtium and water-lily plants. Leaves are sometimes smooth and shiny. In many plants they are covered with hairs of various sorts. The hairs may reduce evapora-

tion and produce glandular secretions, or are sometimes stinging structures as in nettle weeds. The leaves of some plants are modified and perform functions other than the manufacture of food. Some are bud scales that protect the inner delicate cells, spurs in barberry bushes, food-storage structures in onions, water-storage organs in many plants, rootlike structures in water ferns; and some capture insects in pitcher plants. Leaves of underground stems, such as potato tubers, are reduced to tiny specks. The leaves of dodder plants and other vascular parasites or saprophytes are extremely small or completely absent. Most cacti at maturity have no leaves, and the stem contains the chlorophyll plastids.

The margins of leaf blades may be entire and smooth as in corn and dogwood plants. They are toothed when they have indentations that permit water to flow off with ease as in apple and elm leaves. When the indentations are large and coarse we say that a leaf is lobed. Lobes are of all sizes and shapes. The lobes may be indented toward the center of the leaf as in oaks, or toward the base of the leaves as in maples. When a leaf is entire, even though the lobe comes very close to the center rib, we say that a leaf is simple. When a blade is divided into separate leaflets it is called a compound leaf. The leaflets may be attached directly to the petiole as in clover plants, or distributed evenly along the length of the petiole as in walnut trees and rosebushes.

The leaf blade is supported by a system of vascular bundles called veins, which also supply the cells with water and necessary nutrients. The vascular bundles convey the manufactured foods from the leaf into the stem, which distributes them wherever needed within the plant. The veins are arranged in distinct patterns in different plants. In grasses and similar plants the veins run parallel to one another from the base of the leaf to the tip. When the petiole extends into the leaf blade it forms a large central vein called the midrib. In banana leaves the veins run in parallel lines from the midrib to the edges. The veins of plants like maples branch out many times and form a complicated delicate network that extends in all directions. The leaves of such plants as the elm and oak trees have a main midrib from which the network spreads out. The leaves of maple and geranium plants have several large veins of equal size that branch into the blade from the base. A fine network of tiny veins is formed from each one of these ribs. Large veins are usually covered with tough fibers that increase the rigidity of the leaf. Many valuable fibers are extracted from such large veins. Manila hemp comes from a bananalike plant, sisal hemp is processed from agave plants, and New Zealand hemp comes from a relative of iris plants.

The leaf blades of all plants are covered with a layer of skin tissue, generally one cell in thickness. The outer wall of this epidermal tissue is usually thickened and covered with a layer of cutin, which is made up

of wax, and may be further protected with hairs. The leaves of many plants contain glandular cells that manufacture various kinds of substances. The leaves of datura, poison ivy, and water hemlock plants are very poisonous.

Many valuable drugs are extracted from leaves. Tea comes from a relative of camellia plants, the leaves of coca plants produce cocaine, foxgloves give us digitalis, and belladonna and pennyroyal are other valuable leaf drugs. Mint, eucalyptus, clove, and bay leaves are widely used in flavoring many foods. The leaves of tobacco plants are of very great economic importance. Cabbage, lettuce, and spinach plants are important vegetables cultivated solely for their leaves. Beet and turnip leaves are especially rich in many beneficial vitamins. The bud leaves of asparagus, artichoke, Brussels sprouts, bamboo, cabbage, and onion plants are justly esteemed. Silkworms transform mulberry leaves into silk. Many grasses, alfalfa, clover, cow peas, vetch, and many other plants are grown as forage crops to feed animals, who change the tough cellulose and other plant products into meat, fat, leather, fur, milk, and eggs. Draft animals change the radiant energy that was fixed by the chlorophyll bodies in leaves into work energy, and are used to pull farm machinery and to transport us and our goods.

The outer skin covering of leaves is not completely intact, but punctured with numerous pores or stomata that are opened and closed by guard cells (Figs. 42, 65). When leaves lie horizontally they usually have very few or no stomata on their upper surface, and a great number of openings on their undersurface. Those leaves that stand erect have the same number of stomata on both sides. Leaves that grow in the shade usually have larger stomata, but a fewer number than those that are exposed to the light. An inch of leaf surface may contain anywhere from two hundred or less to several hundred thousand stomata.

The movements of the guard cells are influenced by the age and state of maturity of the leaf as well as by water, light, and food factors. When the atmosphere is dry the stomata are usually open, and when saturated they are closed. Guard cells of young leaves are usually more active than those of older leaves, and when a leaf is mature they may lose completely their ability to move. Sometimes a great deal of harm is caused when minute particles of dust and smoke from industrial operations settle in the open stomata and prevent the guard cells from functioning. Unless the stomata are plugged, such an event may cause the death of a plant during periods of drought, because the guard cells are the only mechanisms a plant has to control excessive water loss. Guard cells move at various times in different kinds of plants. Those in the leaves of cereals open during the day whenever there is sufficient light and are closed at night. Plants such as alfalfa, which have very thin leaves, pos-

sess guard cells that are usually open only when the atmospheric conditions are favorable. When the temperature is low and the atmosphere dry, or when there is a lack of sufficient light during the day, the stomata are closed, and then they usually open at night for certain periods. The stomata of most crop plants are open during the day or night whenever the internal and atmospheric conditions are favorable. On

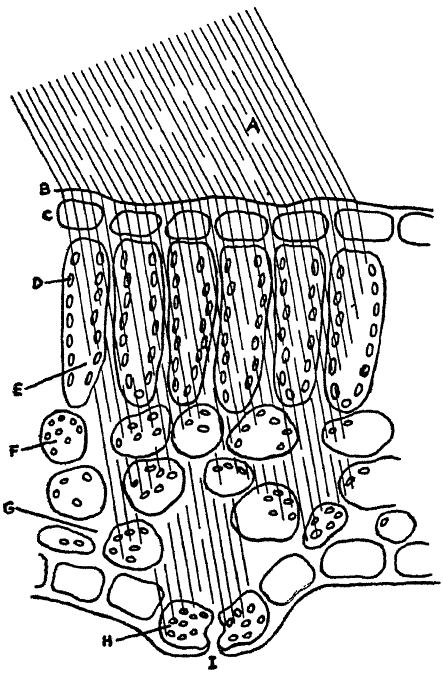


Fig. 65. Cross section of leaf in daylight: (a) light rays, (b) cuticle, (c) skin cells, (d) chlorophyll bodies, (e) palisade cells, (f) spongy cells, (g) intercellular spaces, (h) guard cells, (i) stomata

aging, the guard cells usually lose their power of movement, and the openings remain in one position.

The internal tissues of leaves are so organized as to expose the maximum number of chlorophyll bodies to the light, and are modified in such a manner as to reduce the loss of water to a minimum. A very small amount—usually not more than 5 per cent—of the radiant energy that enters a leaf is used in the manufacture of food. The remaining energy is changed into heat, which evaporates the water surrounding the manu-

facturing cells, and by this means protects them from being overheated. The manufacturing cells are separated from each other by a network of intercellular spaces that permit the circulation of water vapor, nutrients, and gases which the chlorophyll bodies need for their work (Fig. 65). The chlorophyll bodies need a great deal of water in order to function properly. If they lie too near the surface of a leaf that is exposed to direct light, the radiant energy will evaporate too much water. The green plastids assume various positions in the cells, depending upon the intensity of the light that enters the leaf, the moisture conditions within the plant, and the humidity in the surrounding atmosphere.

When a leaf is exposed to strong illumination a great many chlorophyll bodies are formed. These arrange themselves along the sides of the cell walls, which are able to elongate as they are soft and pliable. The elongated cells form the palisade tissue, in which the vertical arrangement of the green plastids minimizes the loss of water and at the same time permits the light to diffuse into the lower cells of the leaf. Leaves that grow in the shade have soft, spongy, round manufacturing cells. They form a few chlorophyll bodies that are arranged in such a way as to increase the number exposed to the light. In the shade, the danger of excessive water loss is slight, while the need of obtaining all the light possible is of utmost importance. This arrangement of plastids is not found only in sun and shade leaves; it is also typical of practically all horizontal leaves. The upper cells of those leaves receive direct sunlight, become elongated, and form palisade cells, while the lower portion receives only the small amount of light that filters down from above, and therefore is made up of round spongy cells. Those plants that have erect leaves equally illuminated from all directions develop spongy cells in the middle and palisade cells on both sides. When many palisade cells are formed the leaves usually tend to be thin and wide. Shady leaves that have a great deal of spongy tissue have a tendency to be thicker and are usually narrow. Upright leaves generally resemble blades. Those leaves that are very thick and have a great deal of spongy tissue are called succulent leaves. Large quantities of water and other substances are stored in these leaves.

In addition to the chlorophyll bodies, many leaves contain a great number of other pigments that give them a very attractive appearance and are used in landscaping gardens and indoor decoration. Begonia, various ferns, agave, alocasia, anthurium, caladium, asparagus, and many other plants are cultivated for their beautiful foliage.

The manufacturing of food—photosynthesis—is not a simple chemical reaction of carbon dioxide and water, but a very complicated, mysterious chain of processes that take place along the surface of green plastids and in the surrounding cytoplasm. The carbon dioxide circulates in the intercellular spaces and diffuses into the manufacturing

cells through the soft walls, where the gas comes in contact with the plastids and water. The carbon and water are united to form the first carbohydrate molecule. Photosynthesis takes place only in light and when there is a sufficient amount of water and carbon dioxide entering the leaf. The surplus oxygen molecules that are not used are released into the atmosphere. An average person uses about the same amount of oxygen that 270 square feet of leaf surface release during the daytime. As soon as a molecule of sugar is formed, either it is passed from cell to cell until it comes to a vein, or it is converted to starch and removed as sugar during the night, freeing the manufacturing cell and enabling it to continue to manufacture more food.

Different leaves and cells have varying amounts of chlorophyll bodies and manufacture various amounts of food in a given period of time. The amount of sugar produced depends upon the kind of plant, amount of leaf surface, habitat climatic conditions, health of the plant, whether the stomata are open or closed, the amount of carbon dioxide that is available, and many other factors. An average leaf has about twenty-seven million chloroplasts in one square inch of palisade tissue, and about six million green plastids in the same amount of spongy cells. An average apple tree has about one hundred thousand leaves. Crops differ widely in the amount of food they manufacture. An acre of corn produces about two acres of leaf surface, which manufacture about two tons of starch or about two pounds per plant. A sunflower plant produces about one ounce of starch per one square yard of leaf surface on a summer day. About 2,700 square feet of leaf surface are needed to produce enough starch to feed one man for one year. It takes about four months for a square yard of leaf surface to make as much sugar as a person would use in one day. An acre of corn will feed 1,000 men for a day, an acre of potatoes 600 men, and an acre of beans 375 men. In order to produce sufficient amounts of the following foods for one person for one year, we must plant a fraction of an acre of bananas and rice, which are the most efficient food producers known; one quarter of an acre of sugar beets; one third of an acre of sugar cane; three quarters of an acre of potatoes; one acre of beans; and one and one-half acres of wheat. In order to supply a cow with enough food so that she can produce the amount of milk consumed by an average person in a year, four acres of forage and grain crops must be cultivated. Fourteen acres of forage plants and grains will yield enough beef to feed an average person.

When a leaf has ceased to function, some of the elements are returned to the plant and may be used again at some later date. The chloroplasts die out, and the other pigments, which were hidden, are seen as yellow, red, and brown autumn colors. A layer of cells called the abscission layer starts to grow on the outside of the node and cuts off the leaf, which is shed. In some desert plants the leaves fall very soon after they

are formed, and the stem, which contains the green plastids, continues the food-manufacturing activities. In annual and perennial herbs the leaves either die as soon as the seeds are formed or are killed by the first autumn frosts. Many perennial shrubs and trees lose their leaves at the end of the growing season in the fall, and make new stem growth and leaves every year. These are called deciduous plants. In the evergreens the leaves remain for several years, some new leaves being formed during growth periods every year, and older leaves, usually when four or five years old, fall off. Most leaf fall occurs during periods of drought.

Certain higher forms of small plants living in bogs, marshes, and other wet places cannot procure a sufficient quantity of nitrogen from the soil. The leaves of such plants have become adapted to capture and devour insects and other small animals in order to supplement their nutritive requirements. These types of plants are called carnivorous or insectivorous plants (Fig. 66). Many are not related to one another, but are members of several plant families. There are about five hundred species of these interesting small plants. They exist in a great variety of

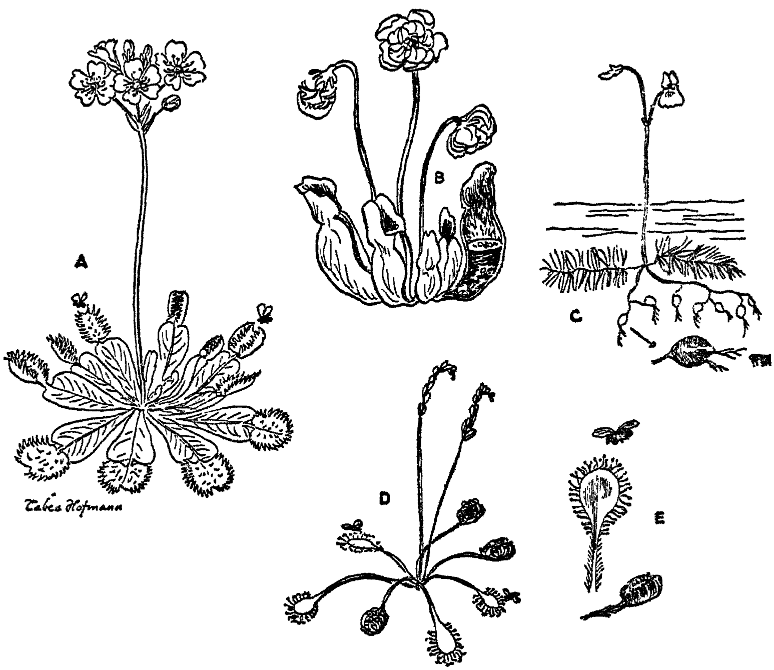


Fig. 66. Carnivorous plants: (a) Venus's flytrap, (b) pitcher plant, (c) bladderwort, (d) sundew, (e) enlarged sundew trap

forms. All have chlorophyll bodies, and when living in a normal soil they are able to grow well without catching the great number of insects they do when they live in damp places.

Butterworts and sundews, which are common in America, and other similar plants have a series of tiny round secreting and absorbing glands that glisten in the sunlight (Fig. 66-D). The insect or animal is attracted by these shiny glands and is caught in the sticky substance and held fast as other hairs fold and close over it. The glands then pour out acids and enzymes that dissolve the soft parts of the insect. When these are digested the gland-bearing hairs open again and are ready for the next victim. It takes from one to four days for such a structure to digest an insect.

The bladderwort is a remarkable water plant that has no roots but floats submerged near the surface with only the flower stalks exposed above the water (Fig. 66-C). The plant has small air bladders that support it. Hairs are arranged around each trap of every bladder, and little snails and other shellfish take refuge among the hairs, push open a little scalelike trap, and are caught inside, where they are digested.

There are many different kinds of pitcher carnivorous plants, the most common ones being Cephalotus, Darlingtonia, Sarracenia, and Nepenthes (Fig. 66-B). Certain leaves of these plants are transformed into pitchers of various shapes and sizes. Some have covers that protect the inner fluids, while others are open. Many have hairs, others soft waxy substances that line the inner portions so that the insect that falls in is unable to leave. These plants have a certain amount of fluid at the bottom of the pitcher, which both attracts and digests the insects. Rain water is able to enter into the open contraptions, and it is prevented from entering into pitchers that have covers. Many pitcher plants have beautiful flowers and their pitchers are of many attractive hues.

The Venus's flytrap plant is restricted to the Carolinas (Fig. 66-A). The small special leaves of these plants lie flat on the ground in the form of rosettes. The trap consists of hinged open leaves that are surrounded by bristles. On the inside of each half lie several sensitive hairs. When these are touched the two sections close together and trap the insect, which is then digested.

Some higher forms of plants that have lost their chlorophyll bodies live either as saprophytes or on dead or decaying organic substances or as parasites on living organisms. Many orchids and members of the Indian pipe family are saprophytes. The dodder, which is a member of the morning glory family, is one of our most common parasites. The broomrape family, which is related to the begonias, is a group of parasites consisting of about two hundred species. A tropical family of plants called Rafflesia (Fig. 67), which is related to the buttercups, has degenerated to such a degree that roots, stems, and leaves are not formed

at all; instead, the seeds germinate into funguslike growths that penetrate into roots and logs. When the plant has accumulated a sufficient amount of food, it forms exposed buds that attain the size of cabbage. When these open, enormous beautiful purple flowers anywhere from three to six feet in diameter are formed. These huge, fleshy, bowl-shaped flowers have five immense lobes and emit a very unpleasant odor.

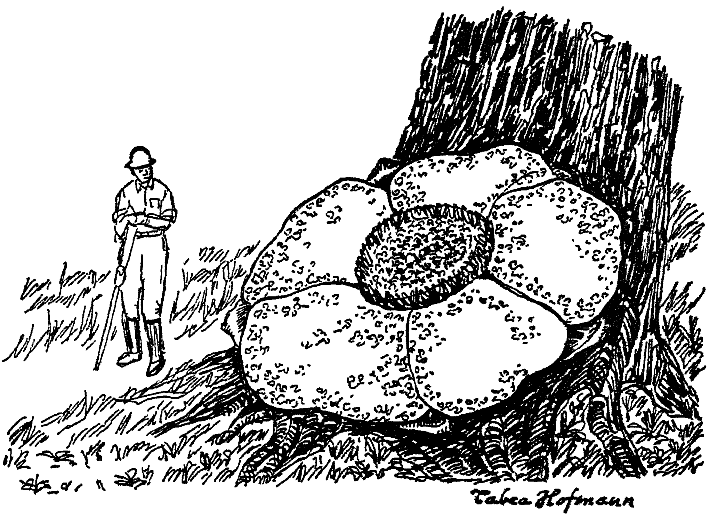


Fig. 67. Rafflesia, the largest flower in the world

All fern plants and their relatives reproduce themselves by forming spores on their leaves. The walking fern develops a small complete plant at the tips of its leaves (Fig. 143). When the young plant is firmly established in the ground, the tip of the leaf withers away and the new plant becomes an independent individual. The leaves of begonia, butcher's broom, bog orchid, and a few other kinds of plants have the ability to form roots, stems, and new leaves when placed in proper damp mediums.

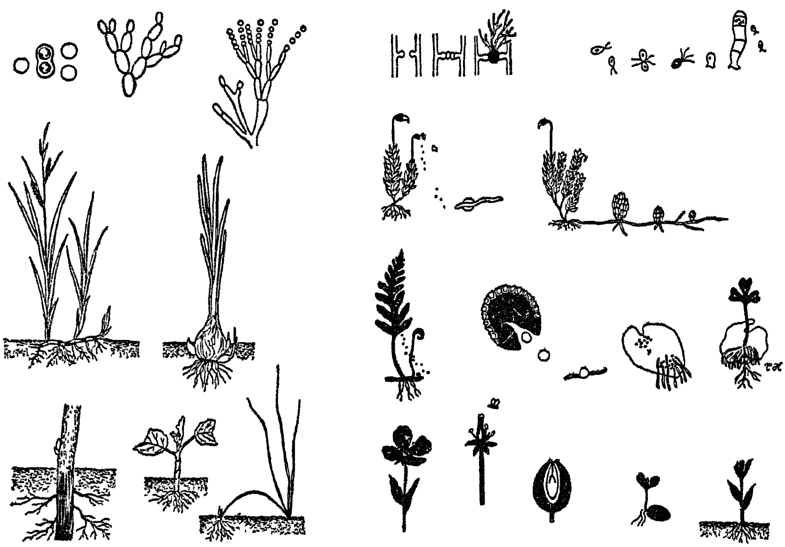


Fig. 68. (Left) Vegetative or asexual reproduction, (Right) sexual reproduction

16: TWO BLADES OF GRASS WHERE ONE GREW BEFORE

EACH living organism starts life as an exceedingly tiny, complete cell, which manufactures more protoplasm. As a cell increases in size it reaches a point where it either divides in two or matures, performs its lifework for a certain period of time, and eventually dies. Nothing that lives is immortal. But before an individual dies it strives to perpetuate its kind by transmitting the hereditary factors it received from its parents to its offspring, reproducing itself and multiplying by vegetative or sexual means (Fig. 68). Many plants are able to reproduce themselves by both methods.

Vegetative, or as it is sometimes called, asexual, reproduction takes place either when a cell divides itself into two or more cells, or when a cell or groups of cells are separated from the body of the plant. Both the daughter cells formed by cell division and the separated cells have the ability to grow into new independent individuals having the same characteristics as their single parent.

The lowest forms of organisms, such as simple bacteria and some

molds, are very elementary bits of protoplasm. They have no definite inner structure and their genes seem to be scattered throughout the living substance. They multiply themselves by fission; the parent cell simply divides itself into two individuals of approximately even size.

The cells of yeast plants and other low forms of vegetation develop one or more outgrowths that are sometimes called "buds." These single-celled "buds" may either remain attached to the parent plant body and form a colony or separate and continue growth as individuals.

The highest forms of single-celled living organisms reproduce and perpetuate themselves by typical cell division (Fig. 40). When the two daughter cells separate they start life as two new independent individuals.

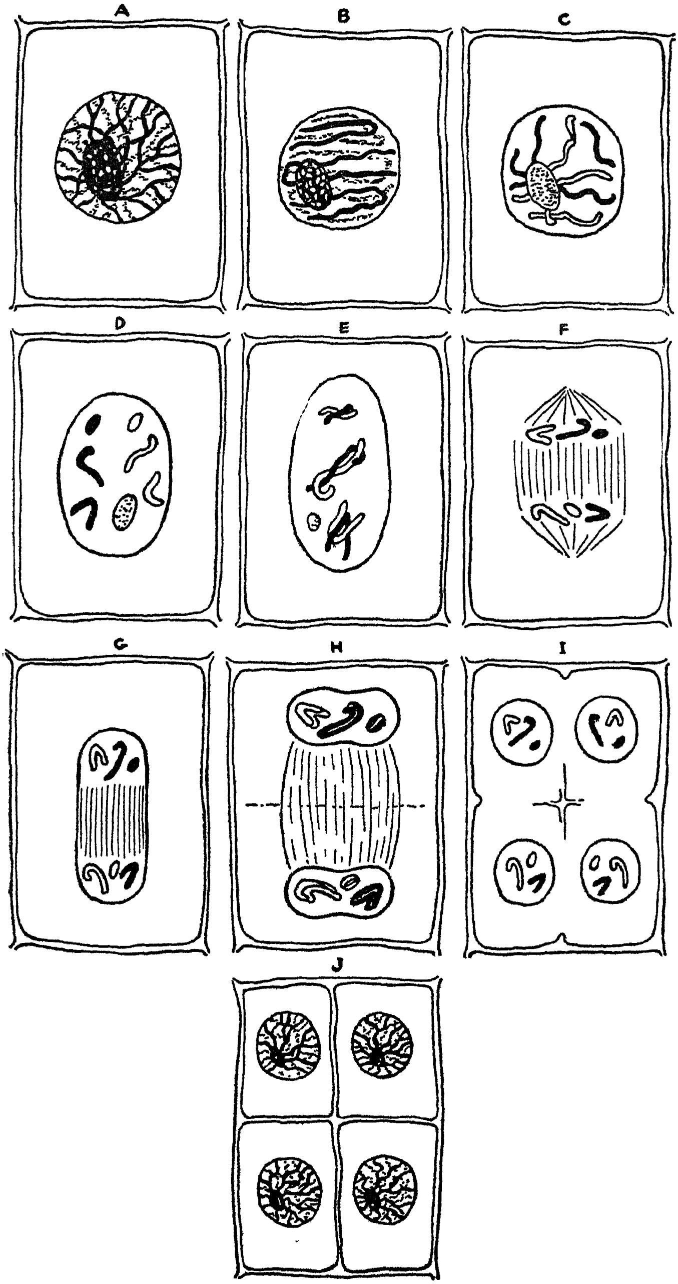
The lowest forms of multicellular life consist of cells that are all similar, and every cell retains its dividing power. Therefore, any cell or group of cells may detach themselves from the parent plant as fragments, and grow by cell division to be new independent plants.

In the highest forms of multicellular organisms only a few cells retain their dividing power. After the earliest stages those that are deposited to become units of the plant body begin to specialize. Some give rise to roots, others to stems and leaves. A certain number do not take part in building the plant body. They change into special cells, or organs made up of groups of cells, which specialize in the manufacture of reproductive units. The vegetative reproductive cells formed are called asexual spores. They arise when special germ cells divide themselves into a few or vast numbers of tiny complete cells. These are released from the parent plant, and in proper environments germinate and grow into new plants by typical cell division either immediately or after a period of rest.

Plants that spend their entire life cycle in water form asexual spores that develop tiny moving hairs that enable them to swim away from their parent and grow into new plants some distance away. These water-swimming asexual spores are called zoospores because they resemble animals in their power of locomotion.

Plants that live in waters that dry out at certain seasons, and those that produce asexual spores in the air, provide their spores with hard durable coverings. Such spores can endure great extremes in temperature and dryness without losing their ability to grow and develop in proper surroundings even after the lapse of many months or years. These types of spores are usually so small and light that they are lifted up and moved great distances by wind and air currents.

Most of the highest types of land plants have groups of special cells that retain their dividing power for long periods of time, at various places in their roots, stems, and sometimes leaves. When any portion of a plant that contains such cells is removed and placed under favorable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conditions for growth, it will develop into a new individual plant. Strawberry plants propagate themselves by forming new plants at the ends of special stems called runners. In some plants creeping underground stems form many buds that grow into wide mats and tufts of vegetation. We are all familiar with the small reproductive bulblets that onions, tulips, and other bulbous plants produce.

The essence of sexual reproduction consists in the union of two gametes to form one complete asexual cell or zygote. The fusion of two masses of protoplasm that continue to grow as a single organism originated in a remote time in the history of living substance and seems to have a stimulating and beneficial effect, especially when the two gametes come from different individuals. Although practically all animals and most plants continue to reproduce themselves by sexual means, many wild and domesticated plants have lost this ability and are able to propagate themselves indefinitely by some form of vegetative methods only.

Practically all plants that reproduce themselves by sexual means pass through two distinct phases or generations during their life cycle. The succession of these two phases is called the "alternation of generations." The first stage starts when a germ cell having two sets of chromosomes divides itself into two special cells, each of which has just a single set of chromosomes (Fig. 69-D, G). These special cells and all the vegetation resulting from their growth constitute the sexual or gametophyte generation, which bears male and female reproductive organs that produce the gametes. As soon as two gametes fuse together and form a zygote, the sexual gametophyte generation ceases to exist. The zygote and all the subsequent growth have two sets of chromosomes and constitute the sporophyte generation. When the sporophyte growth reaches maturity, special germ cells that have been set aside expressly for sexual reproduction divide themselves into special cells which are the beginning of the gametophyte generation. These cells, although having just one set of chromosomes, are not gametes because they are unable to unite to form zygotes, but are only able to form a growth that produces the sexual organs that manufacture the gametes.

Fig. 69. Meiosis—reduction division: (a) Nucleus before division starts to take place; (b) chromatin forms a long coiled thread; (c) chromosomes assume definite number and form; (d) each chromosome arranges itself in center of cell opposite its mate instead of splitting in two; (e) mates meet and entwine about each other (cross-over mutation takes place at this stage); (f) mates separate, one complete set (3 chromosomes in this case) go to one pole, and the remaining set to the other pole. This is the start of the gametophyte generation. (g) Organization of the two new special cells, each having one set of chromosomes; (h) each chromosome splits lengthwise by typical cell division; (i) organization of the four new special cells, each pair being alike; (j) nuclear net is formed and cell walls separate the four new special cells.

Since each member of a gametophyte generation has one set of chromosomes, and the zygote and all vegetation resulting from its growth normally have two sets, there must be a change from two sets to one set, and back again to two sets of chromosomes, sometime during the life history of every organism that is produced by sexual means. This change is effected by a reduction division called meiosis (Fig. 69). If this special type of reduction division did not take place, the gametes would have two sets of chromosomes, the next generation would begin with four sets, the following offspring would have eight sets, and this would continue to an impossible infinity.

The beginning stages of reduction division are exactly the same as those in typical division. Let us say that a certain sporophyte germ cell has six chromosomes. One set of three came from the male parent, and the other set of three from the female. The scattered strings of genes attach themselves and form the long filament that breaks up into the six chromosomes (Fig. 69-C). At this stage, instead of dividing in two, each chromosome seeks out and temporarily pairs with its mate (Fig. 69-E). Instead of there being six chromosomes, there are now three double ones. The chromosomes separate and two sets appear again (Fig. 69-F). Each chromosome now goes to one or the other of the newly formed cells. It is entirely a matter of chance to which of these any single chromosome is drawn. But each receives just one of each kind of chromosome, thereby obtaining one complete set. One cell may get two chromosomes that originally came from the male, and one from the female; and the other cell will receive two that came from the female, and one from the male. Any conceivable combination may take place as long as each receives just one chromosome from each set. These cells may immediately divide one or more times by typical cell division, and eventually produce a growth that manufactures the gametes (Fig. 69-H).

When the sexual characteristics are determined by certain definite chromosomes, as in some plants and practically all animals, including humans, the reduction division of a sporophyte cell will result in the formation of sexually different special cells. One of these will be male, the other female. The gametophyte plants resulting from the growth of these sexually different cells will be strictly male or female plants, producing male and female sexual organs and gametes on separate individuals. When the sexual characteristics are not determined exclusively by the chromosomes but by certain little-understood factors in the cytoplasm, the special cells, although having just one set of chromosomes, will develop into gametophyte plants having both male and female reproductive organs on the same individual.

The sporophyte generation of most plants is bisexual. These kinds of plants are able to bear both male and female organs on the same individual and are call hermaphrodites or monoecious plants. The sexual

characteristics of some plants and the sex of practically all animals are determined by two different chromosomes called X and Y. A female has two X chromosomes (XX), and a male has one X and one Y (XY). When a female gamete, ovule, or egg, which already has an X chromosome, is fertilized by a male gamete or sperm carrying another X chromosome, the resulting fertilized egg or zygote will have two X chromosomes (XX) and the plant or animal growing from that egg will be a female. If the egg (X) receives a male (Y) chromosome, a male will result (XY). The sporophyte generation of these kinds of plants will bear sex organs on different individuals. Such plants are called dioecious plants.

A great variety of sexual reproductive methods are used by plants. There is a regular progression from simple types of reproduction in low vegetation to the very specialized and complex flowers in the highest forms of plant life. These various methods of sexual reproduction are useful in classifying plants.

In the lowest types of vegetation the gametophyte generation produces the prominent growth that we see, while the sporophyte generation is restricted to the zygote, which divides by a reduction division into two special cells soon after it is formed.

Sexual reproduction in one of its most primitive forms consists of simple conjugation and takes place in several low forms of plant life. In other low forms of vegetation the gametes are released from the parent plant. There does not seem to be any difference between them. They appear to be naked bits of protoplasm, all similar in size and structure. The gametes are formed singly or in numbers, either in any cell of a filament, in special cells, or in structures made up of groups of cells. These swimming gametes leave their parent cell chambers, move about in the water, seek one another, and unite in pairs. The uniting and fusion of two gametes is called fertilization. The fertilized egg or zygote so formed may continue to swim some distance before changing into a special cell that continues growth and develops into a new plant.

The mosses and their relatives reveal the formation of a definite sporophyte structure. In the ferns and their relatives the prominence of the gametophyte and sporophyte generations are reversed. The sporophyte is the large, green, prominent, independent plant that has roots, stems, and leaves.

In the highest types of vegetation the gametophyte generation is reduced to almost invisible growths, while the sporophyte generation produces the familiar trees, shrubs, and herbs that cover our forests, meadows, farms, and gardens. The male and the female gametes are formed after special germ cells have divided themselves by a reduction division within many different kinds of specialized reproductive structures, which we call cones, catkins, or flowers. The male gametes are

enclosed in pollen grains that carry the entire male gametophyte generation. The female gametes are produced in ovules. The ovules are formed and remain in elaborate structures called ovaries. When the pollen grain is brought by wind, insects, or other means to the female organ, it develops a pollen tube in which the male sperm descends to fertilize the female gamete in the ovule. The fertilized zygote divides itself many times by typical cell division and eventually grows into a tiny embryo or miniature plant. The embryo develops into a seed when it is surrounded with reserve foods and protective coverings. The ovary becomes thickened and grows into a fruit.

During the life cycle of most plants a point is reached where the rapid period of growth slows up, and the individual produces reproductive organs that will manufacture the gametes. When the growing points stop forming new vegetative growth and change into reproductive structures, the individual dies as soon as its spores or seeds are ripe. This may happen in one season, as in annuals; biennials need two years; and many years are necessary for certain plants like the century plant. Woody trees, shrubs, and certain herbs that grow in favorable locations are able to produce spores or seeds during the course of a few or many years, because special germ cells have been set aside for this purpose.

No matter how long a perennial plant may live, it is eventually killed by some factor. Life is preserved, however, because every type of living organism is able to perpetuate its kind, although an individual may live only a very short time. We can consider asexual reproduction as a peculiar type of growth whereby a small fragment of a plant, in the form of a daughter cell, asexual spore, bud, or cutting, has the ability to regenerate all the missing parts when separated from the parent and placed in a suitable environment.

Sexual reproduction, on the other hand, is an altogether different kind of phenomenon. Even though several seeds may result from the fusion of gametes from the same two parents, each seed will have its unique collection of genes. Offspring from the same parents seldom resemble each other. When a sexually produced individual dies without being reproduced by vegetative means, that particular collection of genes will never again be united.

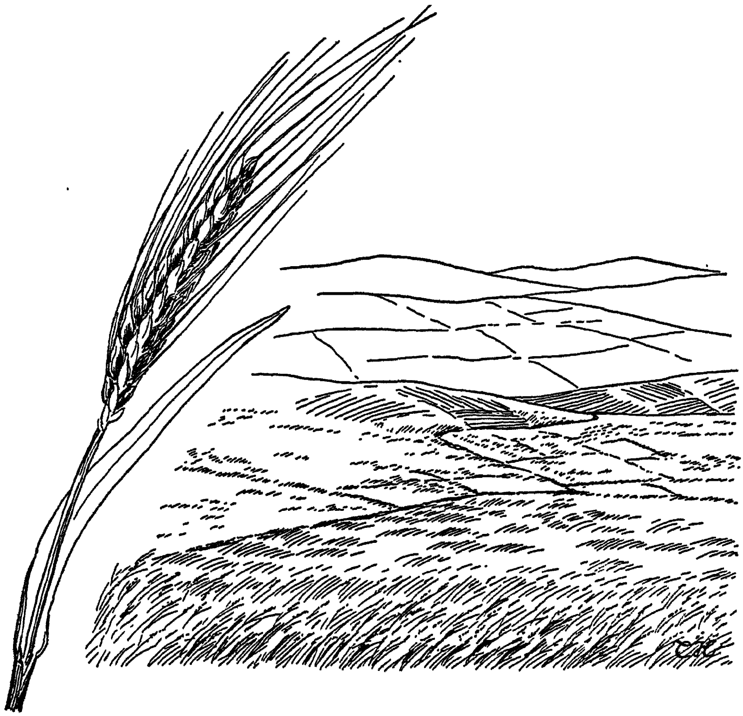

Fig. 70. Wheat grains will invariably germinate and grow into wheat plants.

17. LIKE BEGETS LIKE

THE total inheritance received by a living organism is the sum of all the genes and other living bodies transmitted to it by its parents. Every cell that possesses a certain collection of genes has those special co-ordinating powers that direct it to do a particular type of work and grow in a certain way. When a plant is reproduced by vegetative means, the offspring resembles its parent because the genes have been duplicated and transmitted complete and intact. Therefore, as long as no changes in the genes occur, all forms of life that are multiplied by asexual means have the ability to remain stable generation after generation. Certain bacteria, many molds, seaweeds, and other plants that live in stable environments have retained their characteristics many hundreds, thousands, and in some cases millions of years, and have descended down through the ages unchanged. The many desirable qualities of a large

number of our cultivated plants are perpetuated by vegetative propagation.

Many different kinds of variations may take place as a result of sexual reproduction. The fertilized egg or zygote of every living organism, whether human, plant, or animal, normally contains two sets of genes, which control practically every type of work and activity. These genes are arranged in strings of chromosomes, any one of which came from two different parents. Any single chromosome may or may not have come from any one or all of four grandparents, eight great-grandparents, sixteen great-great-grandparents, and so on backward until the ancestor in which the original gene was formed is reached. Therefore, many irregularities in offspring occur. The same parents transmit different characteristics to each one of their offspring because each gamete receives a different combination of genes.

When a male gamete fuses with a female gamete of the same plant, we say that self-fertilization has taken place. The resulting offspring will resemble its single parent, because the same pairs of genes have been reunited again, unless the parent itself is of mixed heredity. When the fusing gametes come from two different plants, cross-fertilization has occurred. Variations in the offspring are bound to arise because the two corresponding sets of genes have come from two different parents. A certain gene may produce hairs, while its mate may not; one may produce red color, and its counterpart a different color; a gene may originate smooth seeds and its mate may develop wrinkled ones. One gene may dominate its recessive mate. The amount of variation depends upon the different characteristics of the parents and which genes were received by the zygote.

If the two gametes are from closely similar organisms, the offspring will usually resemble both to a remarkable degree. When the male gamete of a McIntosh flower is crossed with the female gamete of another McIntosh, the resulting offspring will be a tree that produces McIntosh apples. Sometimes a successful cross may take place between widely different plants, resulting in offspring that we call hybrids. When we cross a red apple with a yellow one, an orange with a lemon, or a cabbage with a radish, the hybrid may resemble its male parent more closely than its female, the female more than the male, or it may resemble both. Sometimes new characteristics appear in hybrids, producing entirely new kinds of plants.

The only forecast that we can make as to what the offspring will be like when two individuals are crossed is based on the law of averages and determined by pure chance. To clarify the laws of heredity, let us see what happens when we cross two similar plants, such as sweet peas, differing in only one characteristic: color (Fig. 71).

Let us say that one parent has a red-color-producing gene, and the

other parent a white one, and that both genes have the same strength (neither is dominant over the other). The offspring of this first cross compose the first generation. They will all have pink flowers because one gamete had a red gene and the other gamete a white one. When they fused to form the zygote, it received one white and one red gene, producing the pink effect.

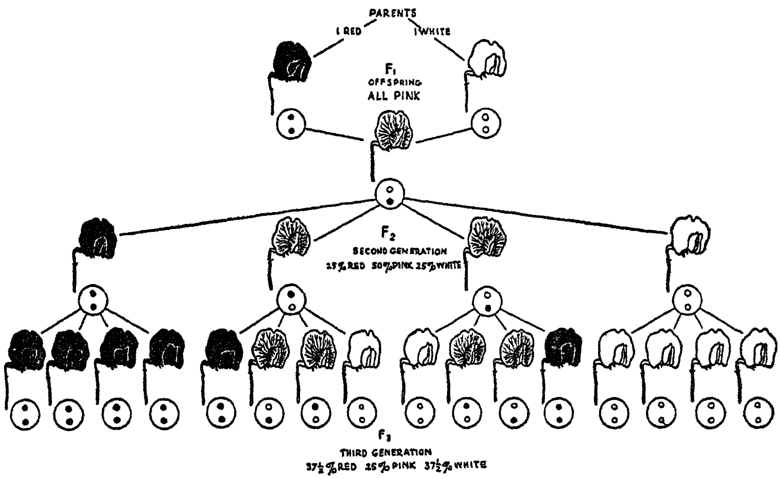

Fig. 71. Chart showing inheritance when there is no dominating gene. Both the red- and white-color genes in sweet peas have equal strength, and whenever they are together in a nucleus the color of the cell will be pink.

Let us now take one male and one female plant of the first generation and cross them. Any two we happen to choose will produce the same effect. These two pink sweet peas will be the parents of the second generation. Let us suppose that each parent produces four gametes. Two male pollen grains with white genes and two with red genes will be produced by the brother. Two ovules containing white and two with red genes will be formed by the sister. When all the male gametes fertilize all the female gametes, four seeds will be produced that eventually will develop into flowering plants. The genes have been separated and recombined again without losing their identity. One plant will produce red flowers because one red pollen grain fertilized a red ovule. Another plant will have pure white flowers because one white gene came together in an egg with another white one. Two will be pink, as one red male fused with a white female, and one red female joins with a white male.

This regular separation of genes in strings of chromosomes when gametes are formed and their recombination in fertilized eggs take place

every time that a new generation is formed during sexual reproduction. The genes and chromosomes normally retain their individuality no matter how many times they are separated and reunited when passed from generation to generation. We cannot tell which particular offspring will get a certain gene, but when many offspring are produced these proportions of one quarter pure red, one quarter pure white, and one half pink —or whatever characteristic a particular gene possesses—will always be constant in the second generation as long as the original grandparents were pure, no sudden changes occurred, and no single gene was dominant over its mate.

When we cross any two white ones again we will get pure white flowers; likewise when we cross the red ones we will get pure red, in the third and in every following generation. These will be pure strains or lines, and will breed true whenever united with a like mate. When we cross any two pink ones we will again get 25 per cent red, 25 per cent white, and 50 per cent pink flowering sweet peas.

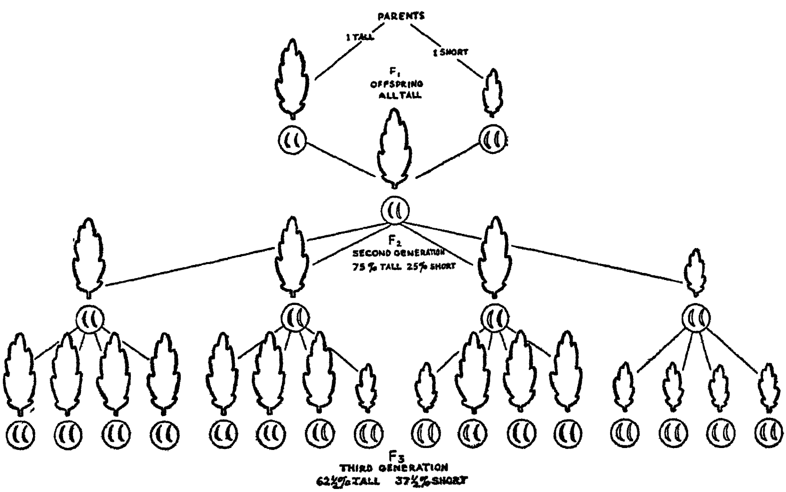

Fig. 72. Chart showing inheritance between a dominating and a recessive gene. Whenever a dominating gene for tallness is present the plant will be tall even though a recessive dwarf gene is present. Dwarfness in this case can result only when two recessive genes are present within the same nucleus.

Often a hybrid is not an intermediate form between two parents but resembles only one of them. This complication arises when one gene of a pair is dominant over its mate (Fig. 72). Thus tall plants crossed with dwarf ones may produce only tall offspring; purple flowers crossed with white may result in plants having only purple flowers; a gene pro-

ducing wrinkled seeds may dominate its recessive mate, which forms smooth ones (Fig. 73).

Let us see what happens when we cross a plant having a dominant gene for tallness with a plant having a recessive mate for dwarfness (Fig. 72). The first generation will all be tall! Every seed produced by the fusion of the two gametes contains one dominant tall and one recessive dwarf gene. The recessive gene, although present, has been unable

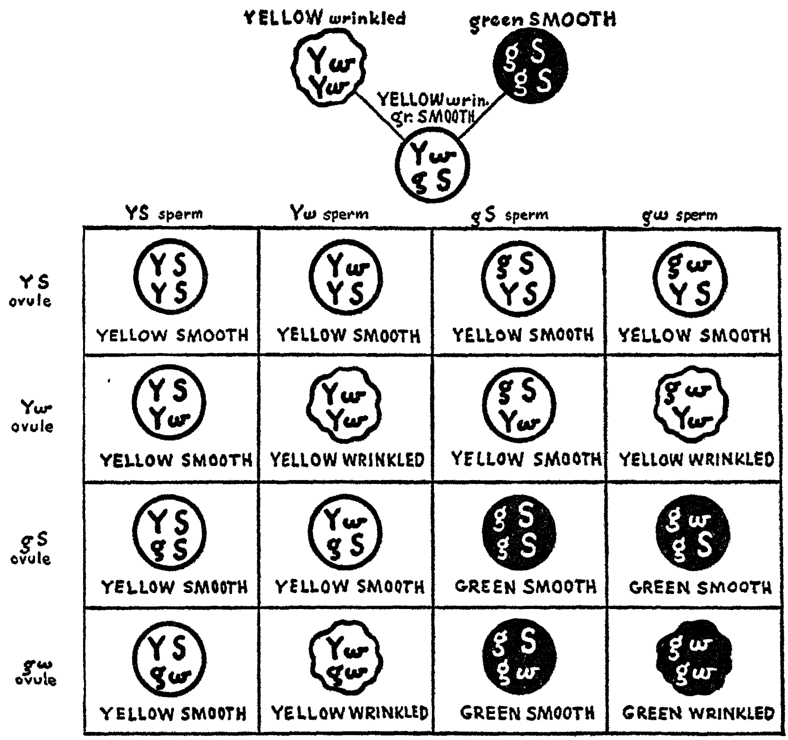

Fig. 73. Chart showing inheritance of four characters when a pea plant bearing wrinkled yellow seeds is crossed with one yielding smooth green seeds

to produce any effect. When the tall plants of the first generation are crossed, four different kinds of combinations will take place, but only one dwarf and three tall plants will be seen. One tall plant will be pure because it will have two tall genes. One dwarf plant will likewise be pure, since it will have two dwarf genes. The other two plants will be tall because they each have one tall gene, which is dominant, and one dwarf gene, which is recessive. When we fuse the tall with the tall and the dwarf with the dwarf, the third and all succeeding generations re-

sulting from these crosses will be pure tall and pure dwarf. When we cross the talls that have the mixed genes, three quarters of the seeds will grow to be tall and one quarter will be dwarf plants.

Every cell carries within itself many genes. A certain number are linked together in each chromosome. When a fertilized egg receives a particular chromosome, it possesses a certain number of controlling factors. If the genes for red color and smooth seeds are on the same chromosome, every offspring that gets such a chromosome will have red flowers and smooth seeds. If these 2 genes are on different chromosomes, 16 different kinds of combinations may take place; 3 kinds of chromosomes may produce 64 combinations; 4 chromosomes 256; and when a cell has 24 chromosomes to make up one set, as in humans, they can combine in 8,388,608 different ways.

All kinds of combinations and recombinations of genes and chromosomes are taking place constantly. At every step along the path of life, every kind of organism changes its individuality each generation. Although the offspring that are produced are very similar to their parents, they are never exactly like them or like each other. When we look at a plant or animal we cannot tell its ancestry by its appearance only. We may think that a certain plant or animal is pure, but it may have many partial and complete, dominating or recessive genes. Therefore the external or phenotype appearance of a living organism may be quite different from its genotype or genetic constitution. The only way we can be sure of the genetic make-up of an organism is to breed it from pure parents, or to propagate it by vegetative means.

Occasionally a certain active cell or a group of cells changes abruptly. These sudden changes are called mutations and are due to variations taking place in the genes, or their arrangement in the chromosomes. There are several types of mutations caused by different factors.

Although we cannot see individual genes, we believe that each one is made up of a special combination of atoms that gives each gene its specific characteristics. Sometimes the arrangement of the atoms becomes disturbed in one or more ways, thereby changing the working power of that particular gene. From time to time new genes may be formed, or old ones may disintegrate and be lost. Genes sometimes may divide themselves more than once, consequently adding one or more genes to a daughter cell or a gamete; if a gene fails to double itself during cell division, the daughter cell or gamete is deprived of a gene.

In some types of plants gene mutations occur frequently, in others they are very rare. When just a single gene changes, is lost, or is added, the mutation taking place is usually very slight. When many genes are changed, gained, or lost, the effect on the cell will be very great indeed. Any individual that is strikingly different from the normal type is often

called a "Sport." Most large and extraordinary mutations are lethal and kill the cell. If the mutation is beneficial, the cell will thrive. All the subsequent growth arising from the division of such a cell will pass the mutation from cell to cell and from generation to generation. Some of our best cultivated plants have arisen as mutations that occurred in cells possessing the power of division. The navel orange originated as a bud mutation on an ordinary orange tree in Brazil. Plant cultivators and breeders are continuously on the lookout for new and better types of mutations, which are selected and multiplied by vegetative propagation.

We do not know how most of the mutations in individual genes occur. We believe that some of them are caused by bombardments of stray cosmic rays and free electrons from unstable atoms, as well as by electrical discharges in the atmosphere and sudden abrupt changes in temperatures and water relations. Scientists have been able to effect certain changes in the genes of several different kinds of animals and plants by using X rays, certain unstable radioactive elements, and various chemicals.

Three different kinds of mutations may take place when chromosomes are actively moving about and dividing at the time that daughter cells and gametes are being formed, and when gametes fuse together during fertilization. The simplest type of chromosome mutation takes place when something happens that misplaces one or more genes from their regular order of arrangement in a chromosome. They leave their normal positions and become attached at other places in the same chromosome. This type of mutation will affect the co-ordinating power of all the genes in that particular chromosome.

A mutation called "crossing over" may occur when two like chromosomes are temporarily united during reduction division. At this stage

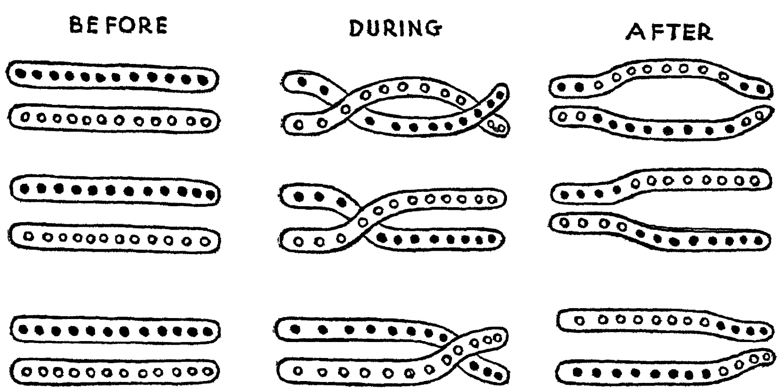

Fig. 74. Cross-over mutations

one or more genes may leave one chromosome and become attached to its mate (Fig. 74). Sometimes an exchange of large sections containing many genes takes place when the two chromosomes are twisted and wrapped around each other and cross each other at one or more points. In some plants such as the Jimson weed, and in certain insects, this "crossing over" or recombination of genes between two like chromosomes takes place with a remarkable order and constancy. All kinds of abnormal growths result from "crossing over," depending on what types and how many genes have been misplaced and what combination is received by the fertilized egg. The many different colors in the leaves, flowers, and fruits of some plants are a result of the exchange of genes during "crossing over."

The third type of chromosome mutation occurs when an entire chromosome either fails to divide or divides itself more than once during cell division. One daughter cell or gamete may receive or be deprived of one or more of its normal number of chromosomes. Let us say that such a mutation has taken place in a cell normally having six chromosomes. When that cell divides it may produce one daughter cell or gamete having five chromosomes, and the other daughter cell or gamete will receive seven. Any combination is possible. This type of mutation occurs frequently in many kinds of plants. Although the normal chromosome number in the cells of corn plants is twenty, cells containing anywhere from sixteen to thirty-eight chromosomes have been found. Iris plants have anywhere from twenty to over a hundred chromosomes, although their normal number is twenty-eight.

Some plants may be made up of cells having three, four, five, six, or more sets of chromosomes. Plants having many sets of chromosomes are usually bigger and richer in vitamins and other substances than normal growths. The best cotton fibers, the finest tobacco leaves, the most nourishing wheat grains, and the largest and most beautiful carnation, chrysanthemum, dahlia, iris, and rose flowers develop on plants that have more than their normal two sets of chromosomes. The increase in the number of chromosomes may be caused by shock, by a grave wound producing injury, or by special chemicals.

Sometimes entire sets of chromosomes double themselves one or more times without any division taking place in the cell itself. One gamete under such circumstances receives two sets. When a gamete with two sets fuses with a normal one, the resulting egg and future growth will have three sets. When a gamete that has two sets fuses with another gamete also having two sets, the resulting egg will have four sets. Many different combinations may take place. We can induce the multiplication of single chromosomes and double complete sets artificially by severely cutting young plants, and by applying heat and various chemi-

cals in the forms of pastes, liquids, and gases to spores, buds, germ cells, gametes, and seeds.

The art of breeding plants had its beginnings at the very dawn of civilization when the first savage selected the most desirable plants as they were growing wild. The domestication of plants started when he planted the best kinds near his tent, hut, or cave, and tended them. Eventually man learned that when he propagated a plant by vegetative means the offspring would resemble its parent, and when he selected the best seeds for planting his harvest would be more successful, but he did not know why. The science of genetics, which strives to answer that question and others, is a very new study that has been developed only within the past fifty years. Today we are able to answer some of the questions and to use our knowledge in the development of better plants and animals.

Fig. 75. Some members of the gourd, grass, lily, and oak families

18. EACH ONE IS NAMED AFTER ITS KIND

IN nature, there are no two individuals exactly alike. We sometimes say that things resemble each other "like peas in a pod," when we wish to express likeness between two similar objects. But if we examine the peas in any single pod very closely, we soon see that we can grade them according to size and weight. One will be the largest, another the smallest, and the rest intermediate, grading down from large to small. We can likewise grade flowers, seeds, fruits, leaves, stems, and roots from the same plant or related plants, animals, and humans, according to size, color, form, structure, weight, intelligence, or any other standards we select. When we examine an ear of corn that has been growing among several different kinds of corn plants, the variations among the kernels will be striking (Fig. 76). There may be dark, light, purple, yellow, white, dented, smooth, and wrinkled kernels on the same cob. As each kernel is the result of the fertilization by a different male gamete, two or more seeds in any ear of corn, or any other fruit that has several seeds, can be alike only when more than one pollen grain from the same male parent or its exact twin fertilized the gametes in the female organ. Although all the seeds in any single fruit have the same mother, they often have different male parents.

The planet on which we live is covered with an endless variety of

living organisms. Botanists have so far discovered, described, and named over three hundred thousand different kinds of plants living on the earth today, and over fifty thousand species of ancient plants that have been found preserved in rocks as fossils. Many new kinds of plants, both living and fossil, are being uncovered every year.

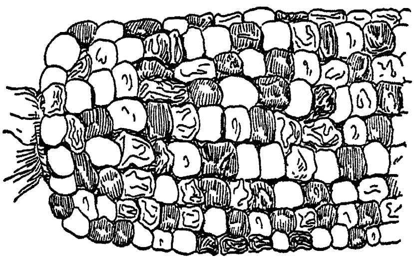

Fig. 76. Variations in kernels on a corncob

Since the beginning of civilization man has tried to classify properly and name the living things that populate our world. His first attempts go back to the very origins of language and are very crude. In those early days plants were classified simply as trees, shrubs, or herbs. Later, all living things having similar external features were united into groups such as bulbs, grains, and melons.

As the study of plant life became more exacting, early scientists started to realize that the descendants of living organisms resemble their parents and ancestors to a very marked degree. Each group retains the characteristics that are used in classifying its members. All wheat plants resemble their ancestors in all the important features, although they may have changed in some characteristics as generation replaced generation. From being purely descriptive in character, classification became based more and more on genetic factors.

The resemblance between groups eventually led scientists to unite several similar ones together into larger groups (Fig. 75). Thus wheat, barley, and oats resemble each other more than they do other kinds of plants, and are therefore members of a larger group. Cucumbers, melons, squash, and pumpkins resemble each other in many features and must have arisen from a common ancestor.

The proper classification of living organisms is a very complicated science because living things did not evolve along a single path of life, but in several definite directions (Fig. 78). Every large group of living organisms is made up of simple, intermediate, and complex smaller groups. The members of each group have solved their individual environmental problems by evolving in their particular fashion. Just as there are low, intermediate, and higher forms of worms, fish, birds, in-

sects, and mammals in the animal kingdom, there are many gradations of seaweeds, fungus growths, mosses, ferns, and seed-bearing plants in the vegetable kingdom. Although one single most complicated and intelligent group, in the form of human beings, has evolved in the animal kingdom, no such single highest and most complicated kind of plant has as yet appeared on this earth.

If we were able to have on hand representative samples of all the plants that have lived on earth in past ages, and all that now populate the world, we would be able to arrange them in regular ascending order as they evolved, and have a complete natural system of classification. Unfortunately we are unable to do so because most of the ancestors of the known present-day and ancient plants have completely disappeared, leaving no trace behind them.

The natural classification of plants is therefore a very difficult science, and many different characteristics and factors are used as clues in helping us to place each kind of plant in proper relation to all the others. Some differences are very striking and easy to describe; others are very minute indeed. Sometimes as many as a hundred or more different characteristics must be carefully compared in order to find the difference between two plants living under similar environmental conditions. In many if not most cases we have to suppose the ancestral parentage without having the proof on hand.

As two similar plants are bound to have the same kinds of cells arranged in much the same manner, the comparison of cells and internal structures is widely used. The presence or absence of certain organs and tissues often gives us valuable information. Similar plants have or lack spines, thorns, hairs, tendrils, leaves, woody stems, flowers, and certain colors. Reproductive organs appear only after a plant has reached maturity, and as they do not last a long time, they are not so greatly affected by changing environmental conditions as leaves, stems, and roots. Plants that have the same kinds of floral structures, seeds, and fruits are usually very closely related. A very important factor that is being more widely used as the chemistry of living organisms is better understood is the chemical make-up of plants and the products they manufacture. All citrus fruits are rich in vitamin C, produce citric acid, and have oil sacs in the skins of their fruits. Practically all the mints are highly aromatic. The leaves and stems of grass plants contain large quantities of silicate. Although we are as yet unable to use the knowledge so far gained from the study of chromosomes and genes in the classification of plants, when the composition, structure, shape, and sizes of these hereditary factors are better understood they will no doubt prove to be invaluable.

The primary unit in the classification of plants, as well as animals, is the individual. It is dependent upon all of its cells and their co-ordina-

tion in order to be a complete single working unit. This co-ordination is achieved by the controlling hereditary factors; chemical messengers in the form of hormones; pigments; and proteins in the form of enzymes, vitamins, and plastids, which are the regulators of various processes. The complete individual as well as each cell is limited in its lifework by the environmental factors, which supply the necessary materials and the proper working conditions. Complications may arise in classifying an individual when several different kinds of plants are grafted together to form one plant. We can have one plant that has almond roots, the stem of a plum, and the branches and fruits of several different kinds of peaches, cherries, and apricots. A complication may also arise when a large part of an individual is removed by an injury, or when cells, tissues, and organs are deformed by insect injuries, disease attacks, and other factors.

All the offspring produced by a single parent plant by vegetative propagation form a clone. A clone, therefore, is composed of the most closely related group of individuals possible. As long as no mutations occur, all the members of a clone are merely separate detachments of a single parent. When a mutation occurs, a new kind of clone may be produced by propagating the changed growth.

When like plants having many characteristics in common are crossed, the resulting offspring resemble their relatives to a very remarkable degree and form what we call a pure line. We use pure-line breeding methods in reproducing animals and plants that cannot be propagated by asexual means in order to conserve desired qualities from generation to generation. A certain strain or pure line can be maintained for many generations. In nature a pure line is hardly possible unless like individuals that can cross are living apart from any others.

When a population is composed of several plants that have a great many, but not all, characteristics in common, they are members of a variety or race. Mankind is divided into the black, yellow, white, brown, and red peoples. Baldwins are one variety and McIntosh another variety of apples. Sometimes we can distinguish between varieties of the same kind of plant by slight differences in habits of growth. Some apples bear fruit at the ends of stems, others on short spurs. Occasionally the differences are very noticeable, especially differences in shapes and colors of leaves, flowers, seeds, and fruits. There are green, yellow, red, and blue varieties of grapes and plums. As varieties of the same kind of plant usually cross with one another with great ease, there are hardly any pure varieties in nature.

As the differences between varieties are often very difficult to recognize, biologists have arbitrarily chosen a species as the basic unit in the classification of plants and animals. A species is a specific kind of organism. Horses, cows, white oaks, sugar maples, apples, and sun-

flowers are names of species. In other words, each species consists of a group of varieties that have similar structure and behavior. Every individual in a given species can readily cross with another member of the same species, but rarely with a member of another species. All the members of each species have the same normal number of chromosomes, and retain their characteristic features through many generations under normal natural conditions. When two different varieties of the same kind of plant are crossed, the offspring retain the characteristics of the species as a whole. A yellow dent corn crossed with a white smooth corn will produce offspring that may have many different kinds of kernels, but they will all germinate into corn plants. In former days it was thought that all the species on earth originated at the time that the world was created, and were not related to one another. Today, through our knowledge of the mechanics of evolution, we know that new species can arise by mutations, and when two different species are crossed, resulting in a hybrid. The tangelo is a hybrid species of citrus that is a cross between a grapefruit and a tangerine. It sometimes happens that varieties become distinct species when they live isolated from other closely related varieties. When the intermediate forms of closely related species have disappeared during the course of evolution, a single species may be strikingly different from any of its living relatives. Corn plants are such an isolated species; therefore, there is only one kind or genus of corn plants.

In order that botanists of all countries may understand each other, every kind of plant is given two names of Greek or Latin origin. These names may describe a specific trait, the place where the plant was found, or some historical or mythological connection, or they may commemorate the botanist who first described the plant. The first name, which designates the genus or kind to which the plant belongs, always begins with a capital letter. The second name is the specific name of the particular species. Sometimes when a certain variety has been under cultivation for many years and its distinctive features have been permanently fixed, a third name designating the particular variety is added. The initial of the botanist who named the plant is usually added at the end. When there are many closely related species, as in maples, oaks, wheats, and a host of other plants, they are members of a single genus. The Latin name for oak is *quercus,* and white oak has the name of *Quercus alba L. Alba* is the word for white in Latin, and L stands for the great botanist, Linnaeus, who originated this binominal system of naming plants and animals. Almonds (*P. communis*), apricots (*P. armeniaca*), sweet cherries (*P. avium*), peaches (*P. persica*), and plums (*P. domestica*) are grouped together in the *Prunus* genus because they are all very closely related and have many features in common. The *Allium* or leek genus is composed of chives, garlic, leeks, and onions.

A group of closely related genera form a plant family. The names of families usually end in "aceae." The apple (*Malus*), pear (*Pyrus*), plum (*Prunus*), rose (*Rosa*), raspberry (*Rubus*), and strawberry (*Fragaria*) genera are all members of the Rosaceae family. Although there are marked differences between these genera, they all have certain reproductive traits in common, and manufacture some similar chemical products.

An order is a large group of related families that have certain features in common, although they differ in many respects. The names of orders end in "ales." Orders are grouped into classes, the names of which usually end in "ae." For example, green algae is one class and brown algae another. Classes in turn are grouped into the main divisions of the plant kingdom.

Because of our present limited knowledge of the relationships of plants, it is quite impossible for botanists to classify the plant kingdom into perfect, natural, and final groups. So many intermediate ancestors are missing, and the personal judgments of many botanists differ to such a great extent that every system is a temporary one that is continuously being revised as new knowledge is acquired. A classification system in vogue for many years divided the plant kingdom into two divisions. The cryptogams were plants that reproduced themselves by spores only, and the phanerogams produced seeds.

One of the accepted modern systems divides the entire plant kingdom into two major groups. The first and most primitive group is made up of all the simple thallus plants, which have no true roots, stems, or leaves, and their gametophyte generation is usually the conspicuous growth that we see. The second group embraces all the vascular plants. These have true stems that contain specialized conductive tissues in the form of either scattered vascular bundles or layers of true wood. The sporophyte generation of these plants forms the independent, green, land vegetation, while the gametophyte is reduced to a very small inconspicuous growth.

It is practically impossible to reconstruct the ancient history of the thallus plants, because the few traces of the fossil remains that have been uncovered are unrecognizable. These types of growths have soft bodies that rapidly decay and do not preserve well. Furthermore, their earliest ancestors are imbedded in ancient rock formations that have undergone many chemical and other changes, which completely destroyed any fossils that may have at one time been present. The thallus plants are therefore divided into two divisions, each of which is comprised of many different kinds of plants that are only distantly, if at all, related. The first division, Thallophyta, embraces the algae, fungi, and lichens. The mosses, liverworts, and hornworts make up the Bryophyta division.

Until recently the vascular plants were divided among three huge divisions. The pteridophytes embraced all the lycopods, horsetails, ferns, and their allies; gymnosperms, all the naked-seed plants such as the cycads, conifers, and their relatives; and the angiosperms, all the true flowering plants.

The many excellently preserved fossil remains of some of the ancient ancestors of the vascular plants have enabled scientists to reveal a little of the early evolution of these plants (Fig. 78). It is believed that the psilophytes, or forms resembling them, were the first green independent land sporophytes. These were very small vascular plants that dominated the land vegetation over four hundred million years ago. It seems that these kinds of plants evolved in several directions: the Lycopsida, which comprise the club mosses and their allies; the Sphenopsida, which are today represented by the horsetails; the Pteropsida, which embrace practically all of the common plants that form the most conspicuous part of the earth's vegetation today; and several other groups of plants that have long since disappeared.

The Pteropsida are divided into the Pteridophyta, which include the ancient and present-day ferns, which reproduce themselves by spores; the Gymnospermae, which form their seeds on the exposed surfaces of special reproductive leaves that are arranged in a spiral fashion around short special stems to form cones; and the true flowering Angiospermae, which develop their seeds within special protected structures called ovaries.

The Gymnospermae embrace the Pteridospermae or Cycadofilicales, which comprise the ancient cycad or seed ferns, which have long been extinct; the Cordaitales, which formed the dominant vegetation about two hundred fifty million years ago and no longer exist; Ginkgoales, which are today represented by a few cultivated park trees; the Cycadophyta or sago palms and their relatives; the conifers, which include the pines, sequoias, and their allies; the Gnetales, which are a relatively new group of plants that are very sparsely distributed in the tropics; and the Bennettitales, which were primitive flowering plants believed by some to have been the direct ancestors of our modern Angiospermae.

The modern true flowering angiosperms are divided into two groups (Figs. 164, 165). The Dicotyledones form seeds whose embryos have two rudimentary leaves. They are represented by hardwood trees such as the oaks, magnolias, and maples, and practically all of our common fruit trees, shrubs, and herbs, such as the buttercups, roses, mints, figs, oranges, mustard, grapes, potatoes, carrots, and dandelions. The Monocotyledones have one seed leaf only and are usually, with the exception of palms and giant bamboos, small herbs. The grasses, lilies, and orchids are some of our most common monocots.

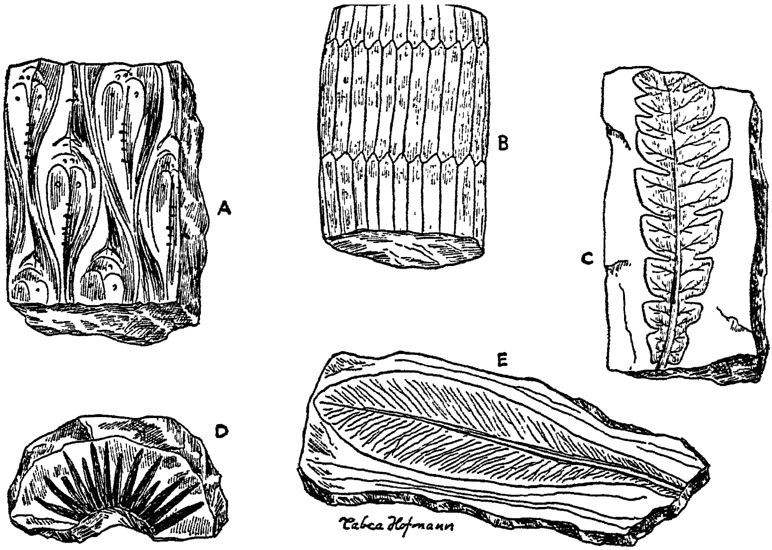

Fig. 77. Impressions and fossil fragments imbedded in stone: (a) lepidodendron, (b) calamite, (c) seed fern, (d) Sphenophyllales, (e) glossopteris flora

19. THE RECORD OF THE ROCKS

THE present condition of the world and its inhabitants is a result of various changes that have been taking place in the earth's crust, on its surface, and in its atmosphere since its creation. Changes are said to be constructive in nature when matter is built up, and when simple substances and living organisms are transformed into complicated structures. Destructive changes occur when large and complicated structures are broken down into smaller and simpler units. When matter alters its position in space, another kind of change takes place.

If all matter moved about continuously no structures could be built up, and if it were permanently fixed in place nothing could be broken down. If all changes continued to be constructive only, our earth would be a huge solid mass of tightly compacted matter, and if breaking-down processes were not checked everything would eventually end up as rays of energy. The succession of building up, breaking down, and rebuilding, and the appearance, disappearance, and reappearance of any substance or event, is known as its cycle. The innumerable kinds of cycles existing in nature are so perfectly and magnificently co-ordinated that

life on this earth is made possible and is enabled to renew itself every generation. We are all familiar with economic, epidemic, and climatic cycles. The alternate rising and falling of the tides, the continuous alternation between day and night, the reappearance of the full moon once every twenty-eight days, and the continuous annual successions of spring, summer, fall, and winter are some of the conspicuous natural cycles. Many cycles such as those dealing with the circulation of the elements, the movements of the stars, and the rising and lowering of mountains and seas can be detected only after long and very painstaking observation and study.

The sedimentary rocks that make up a large part of the earth's outer crust were laid down in successive stages during the course of history. They reveal that certain events reoccurred many times. Each layer consists of a certain thickness of various materials that were at one time exposed as mountains, broken up into stones, ground down into fine particles, changed by various chemical processes, physical forces, and living organisms, and later moved and deposited in seas and lakes, where they were pressed and hardened into stone. Some of the undisturbed formations reveal evidence of their origin, the length of time they were exposed, and considerable information about what occurred while they were a part of the exposed landscape lying on the surface of the earth: the climatic conditions that prevailed, the earthquake, volcanic, and other disturbances that took place, the kinds of living organisms that existed, and various other events.

It has been estimated that the first sedimentary rocks were laid down about two billion years ago. By the study of the successive layers it has been found that the lowest formations do not contain any remains of living organisms, and it is believed that about half of geological time passed before the first definitely recognizable forms of life came to be.

Preserved in some of the subsequent layers are fossil remains of a very few plants and animals that were living on the earth while the rocks were being formed. These preserved remains are a result of rare accidents that have prevented the decay and breakdown of certain plant and animal parts, or are impressions and molds that have remained undisturbed down through the ages.

The reconstruction of certain species of ancient plants and animals is very difficult and often incomplete. Although we may not be able to reconstruct some ancient plants and animals as they were, we often have a good idea of what their general appearance may have been. Those parts that fit together so well that they seem to come from like individuals have been described, named, and classified into small and large groups.

The total thickness of stratified rocks varies from nothing in some places to perhaps ten or more miles in others. If an unchanged portion

of each layer that has been deposited during the entire course of history could be brought to one place, and these formations piled up one on top of the other, they would make a mountain about a hundred miles high.

Geologists and other scientists who study plant and animal fossil remains are continuously uncovering new specimens and other revealing features, which they arrange in regular sequence. Their goal is to have a complete record of all the events that took place, and to have a representative collection of all the forms of life that have inhabited the world since its creation. Even now, some of our present-day living plants, animals, and humans are being trapped and buried in ice, mud, bogs, lakes, seas, and other suitable places where they will not decay, and will change into the preserved fossil representatives of our age in the future. Of course, no single place in the world contains a complete record, and only a small part of the entire history will ever be known.

By the comparison of various differences between fossil remains that have so far been uncovered from many different layers of sedimentary rocks, it has been found that each group of plants and animals passes through three phases in its history. Each genus, family, and higher group appears at first as a very small part of the population of the world, develops and spreads over a large area until it reaches a period of maximum abundance, and then starts to die out as it is replaced by another, usually more highly developed group, and may finally vanish completely. During the continuous evolution of life different plants and animals lived at different periods in the earth's history, and all those that have disappeared have never reappeared again. Unlike most nonliving matter and events that undergo cyclic changes, it seems that living organisms continue to progress, and each geological age supports a higher type of life than the previous one. A few simple organisms of the past ages seem to have given rise to the many relatively complex land flowering plants and warm-blooded animals that dominate the world today.

During its history the earth has experienced long spells of mild climatic conditions and quiet stability of the crust. These normal conditions have been interrupted on several widely separated occasions by short revolutionary periods of great unrest. At these times great changes in the earth's crust, in its landscapes and climates, took place. There were devastating upheavals, shattering earthquakes, terrifying volcanic eruptions, and great climatic changes. On several occasions temperatures descended to such low degrees that many plants and animals were killed off, and great accumulations of ice covered large areas of the world.

Geologists tell us that we are now living in the midst of or are just emerging from the fourth great geological revolutionary period. These scientists believe that the upheavals that have recently occurred raised

land higher and formed more and bigger mountains than the world had ever seen.

Today we are probably experiencing a greater diversity in climates and the earth has a wider range of habitats than previous ages have ever experienced. It seems that the earth is now populated with more kinds and higher forms of living organisms than it has ever previously supported.

The great geological revolutions and other happenings that have marked the passing of the ages have left evidences of their presence. As the revealing folds, scars, fossils, and accumulations of all kinds are situated at different levels, scientists have been enabled to devise a chronological scale of geological time. The earth's history is divided into five great eras, each of which begins or ends with a revolutionary period of great unrest. As the great revolutions have not been evenly spaced in time, the different eras are of different lengths (Fig. 78).

During each era land masses have been invaded by the seas on several occasions. These invasions have occurred in great cycles. Each cycle began with the slow advance of the seas over the land and ended when the land again emerged from the waters. When land was exposed certain types of land plants and animals were able to thrive. Many of these were killed off when the waters invaded the land. At the beginning of the next cycle the survivors multiplied, spread, and evolved into new kinds of creatures and vegetation. Owing to these and other factors, the fossils that were deposited during each succeeding cycle differ in many respects. The orderly sequence of appearance, spread, and disappearance of certain dominant forms of life in one cycle, and the subsequent appearance of new kinds of plants and animals in the following cycle, have enabled scientists to divide eras into periods (Fig. 78). Each period comprises a definite system of rocks that were laid down during one or several cycles. The periods are further divided into stages or epochs of time during which beds of rocks were deposited. Each bed is recognized by the presence of certain characteristic species of plants and animals. The stages are further subdivided into smaller categories.

The "Most Ancient" (Archeozoic) era starts when the first deposits of sedimentary rocks were laid down about two billion years ago, and ends with a revolutionary break about 900 million years later. The huge amounts of rocks that were formed during this tremendously long period of time have so far not yielded any fossils. Graphite, a certain form of carbon, which has been uncovered from some of those rocks, must have come from some type of primitive life forms that had very soft bodies. The remains of these elementary organisms were so completely changed by many chemical transformations, and so greatly disturbed

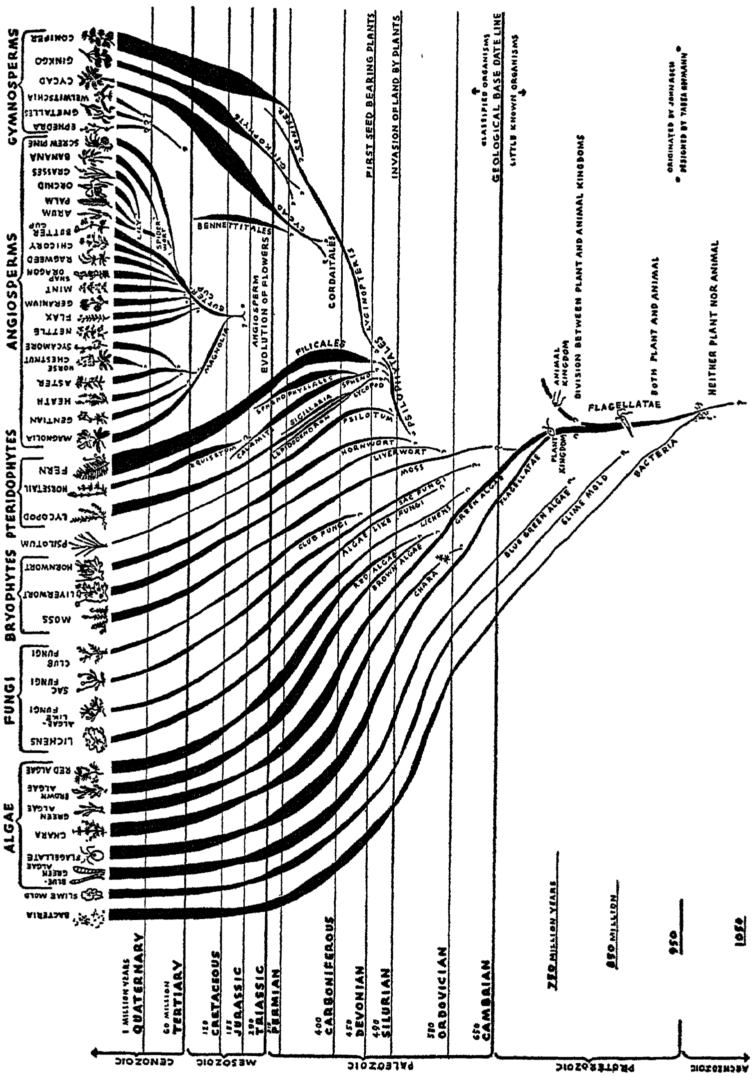

Fig. 78. Evolutionary chart of the plant kingdom

by terrific upheavals and other movements, that they are unrecognizable.

Some traces of what are believed to have been ancient primitive forms of seaweed, slime molds, sponges, and worms have been found in some of the upper layers of the second or "Dawn of Life" (Proterozoic) era, which lasted about 450 million years.

The rocks that were deposited during the 360 million years that the "Ancient Life" (Paleozoic) era lasted have yielded many fossils showing a regular ascending evolutionary trend of life. The first period of this era, which is called the Cambrian, started about 650 million years ago. It is used as the geological base date line because the sedimentary rocks formed during this and all the succeeding periods contain some excellently preserved fossils that can be recognized, named, and classified.

During the Cambrian period most of the United States was covered with water. A few hardy, adventurous, inconspicuous lichens grew on some of the hard exposed rocks, which were otherwise barren of life. The seas were populated with many kinds of seaweeds, plants, and animal reef builders, small primitive animals called tribolites, which have since completely disappeared, and a few shell animals that slightly resembled our modern clams. Unrecognizable traces of many other kinds of plants and animals that had soft unpreservable parts have been found.

During most of the Ordovician period, which started about 580 million years ago and lasted 90 million years, the United States was a low flat swampy land. Many kinds of green algae and marine backboneless and shell animals thrived. The first backboned animals in the form of primitive fishes started to appear. Some of the living organisms of those days seem to have been made up of gummy and oily materials. When these plants and animals were covered by sediments, the oils seeped down through the porous outer crust and collected in large underground pockets. By various processes these oils were changed into pools of petroleum. The latter part of this period was marked by many crustal upheavals, earthquakes, and volcanic eruptions.

The first land plants in the form of Psilophytes and other primitive vegetation started to appear in the Silurian period, which began about 490 million years ago. The fossils of many marine shell animals, coral builders, and fishes have been uncovered from rocks that were formed during those ancient days. In the United States there were many desert areas, and huge deposits of salt were laid down in New York and Michigan. The lands that are known today as the British Isles and the Scandinavian countries underwent a great revolutionary period of crustal unrest.

The Devonian system of sedimentary rocks is sometimes called the Old Red Sandstone period because in some parts of the world red sandstone deposits were laid down. The fossil remains that have been uncovered from the sedimentary rocks and coal formations deposited during this period are of the utmost importance to paleontologists—which is a name given to scientists who study ancient life forms—because both plant and animal life evolved rapidly and became firmly

established on land during this great evolutionary period, which lasted 50 million years. During those ancient days of about 420 million years ago the land was covered with a lush vegetation that gave a new beauty to the landscape. If we were to give a value of 100 to the course of evolution from the creation of life to its present stage, we would estimate that about 70 per cent of that advancement had already taken place by the end of the Devonian period. Bacteria, slime molds, algae-like fungi, and many types of green algae were present. The ancestors of our present-day mosses, liverworts, lycopods, horsetails, ferns, naked-seed-bearing plants, and many other kinds of ancient plant life that have since disappeared were well established and widely spread. Some of these plants were over forty feet high and had trunks three feet in width. Zoologists call this period the "Age of Fishes" because they were the dominant animals of the world. There were also many primitive spiders and insects, and the first amphibians started to invade the land.

The Carboniferous age started about 400 million years ago, and lasted about 85 million years. American geologists divide this age into two periods, the lower or Mississippian, and the upper, which is called Pennsylvanian. It is known to students of animal life as the "Age of Amphibians." Many of the amphibians living in those days were over ten feet long, while our present-day frogs are only a few inches in length. In many parts of the world there were great areas of poorly drained, flat, swampy land that supported a vast vegetation. It was during this age that there appeared the ancient ancestors of our present-day ferns, club mosses, and horsetails, as well as many kinds of seed-bearing plants such as the Cordaites, which were huge trees that have long since disappeared. Many of them were about a hundred feet high and four or more feet in diameter. Tremendous forests composed of these plants were buried in lakes, marshes, and bogs, where they were changed first into peat and later into coal. The coal deposits formed during this age cover over 250,000 square miles in the United States alone. Tremendous quantities of petroleum and gas were also formed and deposited in the earth. There were many giant insects in those days. A fossil of a huge dragon fly that had a wing spread of two and a half feet has been found. The first reptiles started to appear during this great and quiet age.

The "Ancient Life" (Paleozoic) era closed with the Permian period about 290 million years ago. During this entire revolutionary period, which lasted about 25 million years, the earth was greatly disturbed by terrific upheavals, the shifting of land masses, and important climatic changes. It is believed that at the beginning of this period the continents were either closely attached to each other or were connected by

wide strips of exposed land linking Siberia to Alaska, Greenland to Canada and Europe, South America to Africa, and Australia to Asia. It seems that North America, Greenland, and Europe formed a single continent, which has been named by different authorities Algankia, Laurentia, Eria land, or the North Atlantic continent. The Scandinavian countries, known as Baltica land, formed a large land mass that was attached to Europe and extended northward into the polar regions. The northern part of China, Manchuria, a large section of Siberia, and Alaska formed the third Northern Hemisphere continent, called Angara. The entire Northern Hemisphere was separated from the Southern Hemisphere by a broad waterway, known as the Tethys Sea, which connected the western part of the Pacific Ocean with the eastern section by covering what is known today as Central America, southern Europe, North Africa, and the southern part of China. The only vestiges left of that former vast water barrier are the relatively small Mediterranean, Black, and Caspian Seas. South America, Africa, Arabia, India, Indo-China, and Australia formed a single huge continent that has been named Gondwana land.

During the Carboniferous period, while the lands in the Northern Hemisphere were enjoying a mild moist climate and were covered with a rich forest of vegetation, Gondwana land in the south was experiencing a severe ice age. These cold southern lands were supporting a small, widely scattered, cool-climate, fernlike, seed-bearing plant life known as the Glossopteris flora. As the Northern Hemisphere lands started to cool during the beginning of the Permian period, and the ice cover moved northward, some of the Glossopteris flora and Gondwana-land animal life migrated northward and became established in China, Siberia, and other northern lands. By the end of the Permian period the connecting passages between some of the land masses became inundated, and other continents shifted from their original positions and spread apart. During the succeeding ages, by very slow and continuous movements, the present-day positions of the oceans, seas, lakes, islands, and continents came into being.

Most of the huge trees and other forms of lush vegetation that thrived during the peaceful Carboniferous period in the Northern Hemisphere were killed off and replaced by small seed-bearing ferns and other types of plant life that were better able to withstand the new cooler and drier climatic conditions. These became the ancestors of a new type of vegetation that became prominent, in turn, during the next era. There were many different kinds of insects, fishes, and amphibians. Many reptiles were large beasts that had sharp teeth with which they were able to hold and tear apart their prey. The primitive ancestors of the present-day warm-blooded mammals started to appear.

The "Middle Life" (Mesozoic) era started about 290 million years ago with a continental uplift that raised most of North America well above sea level. During the Triassic period there were many large forests of cone-bearing, coniferlike trees that were well over a hundred feet tall and more than ten feet in diameter. The protoplasm of the cells of some of these trees was replaced by silicate, lime, and other substances, which changed the woody trunks into stonelike agate. Some of these beautifully preserved trees are exposed and form the Petrified Forest of Arizona. True ferns, conifers, and many palmlike trees called cycads started to replace the "Dawn of Life" plants. The reptiles evolved into huge terrifying beasts, called dinosaurs, that were to dominate the world for about a hundred million years, eventually disappearing for unknown reasons. The first true mammals came into being. They were small, inconspicuous animals that lived in trees, and were held in check by the dinosaurs. Nevertheless, they continued to develop because of their high intelligence.

During the Jurassic period, which started about 156 million years ago and lasted 60 million years, the cycads, conifers, ginkgos, ferns, and curious primitive flowering plants called Bennettitales were widely spread all over the world. Botanists call this period the "Age of Cycads," and zoologists call it the "Age of Reptiles."

The "Middle Life" era closed with the Cretaceous, or White Chalk period, about 60 million years ago. The flowering Bennettitales completely disappeared, and the ginkgos and cycads were reduced to very small and infrequent growths. Many important coal deposits were formed. The mosses and their allies, which were slowly evolving since the middle of the Devonian period, started to increase. The first true angiosperms, such as the buttercups, magnolias, maple, birch, walnut, poplar, fig, laurel, English ivy, holly, sassafras, breadfruit, and giant redwood sequoia, arose and slowly covered the North American continent. Many flowering plants began to appear, and their floral parts evolved together with bees, other insects, and some birds. During this period the land areas of the world were probably smaller than at any other age, there were great crustal upheavals, and many mountains were formed.

In former days geologists and other scientists who studied fossil remains divided the history of the earth from the Cambrian to the present period into four life eras. The Paleozoic was called the "First Era"; the Mesozoic was the "Second Era"; then came the Tertiary or "Third Era"; and the epoch that started a million years ago was called the Quaternary or "Fourth Era." Today the Tertiary and Quaternary deposits are grouped together under the "Recent Life" (Cenozoic) era,

which is divided into the Tertiary and Quaternary periods. Each of these is subdivided into several epochs.

The Tertiary period is known as the "Golden Age of Mammals." During the five epochs of this age, which began about 61 million years ago, the ancient plants and animals started to disappear. The angiosperms evolved into the modern flowering plants, and the mammals into the animals and humans that dominate the world today.

The "Ancient Recent" (Paleocene) epoch lasted 5 million years and was marked by great upheavals and other movements during which the waters receded and exposed the continents as they are today. The earth started to be divided into many geographical and climatic zones. Today each of these zones has its special types of habitats and is populated by several dominant kinds of plants and animals, which evolved in that zone or migrated from localities having similar features. In nearly all ages preceding this period the various types of plant and animal life were distributed all over the world, and were not restricted to limited localities.

During the "Dawn of Recent" (Eocene) epoch, which endured 20 million years, the northern polar regions enjoyed mild climatic conditions. Over three hundred different kinds of modern plants have been uncovered from deposits formed in Greenland alone. Many hardwood forests composed of beeches, dogwood, walnuts, maples, and elms, and other plants such as the acacia, plums, palms, bananas, water lilies, and a vast variety of ferns were widely spread over the North American continent. Primitive ancestors of our modern dogs, camels, pigs, horses, and monkeys started to appear. It has been estimated that about 3 per cent of the plants and animals that lived during this epoch are present on the earth today.

The seas started to gain ground again during the "Slightly Recent" (Oligocene) epoch, which began about 36 million years ago and lasted 16 million years. Among the new kinds of plants that appeared were the poppies, dates, flaxes, and olives. Many coral-reef-building plants and animals were very active. Some plant-eating animals started to develop sharp pointed teeth and became animal eaters. Giant pigs, primitive horses, other hoofed animals, and saber-toothed cats arose.

Both plants and animals became distinctly modern during the "Less Recent" (Miocene) epoch. The seas receded at the beginning of this epoch, about 20 million years ago, and advanced again 13 million years later. The Alps, Himalayas, and other mountain chains started to be formed. Catkin-bearing trees were very abundant, and the fossils of many stone fruits, hawthorn, and ash trees have been uncovered from rocks laid down during these times. Many plants similar to our modern grasses, pines, and oaks have left their traces as fossils. The development

of grass-covered plains formed a new type of environment for the grazing animals that began to evolve then. The vegetation was very luxurious during this epoch, probably because of the heavy rains and damp conditions that prevailed. Primitive kinds of rodents, dogs, camels, antelopes, and elephants were very abundant.

The Tertiary period ended with the "More Recent" (Pliocene) epoch, which began 7 million years ago and lasted 6 million years. The Rocky, Appalachian, and other high mountain chains were built up. There was an increasing number of present-day plant and animal species living, only a few of which were preserved as fossils owing to the great crustal upheavals that occurred. Among the few recognizable plant fossils found are cinnamon, peach, and water chestnut, and such animal remains as foxes, bears, seals, pigs, and early horses.

The Quaternary period started a million years ago and is known as the "Age of Man." The "Much Recent" (Pleistocene) epoch experienced four great ice ages, during which large areas of the Northern Hemisphere were alternately covered by tremendous glacial deposits and then uncovered as the ice receded. Each period of advancing ice is called a glacial stage, and each time of retreat an interglacial stage. At its maximum the icecap covered a great part of North America—the area north of a line extending from New Jersey, swinging northward nearly to the Canadian border in Montana, and reaching the Pacific near Seattle, Washington. The interglacial stages were long periods of time during which the polar regions enjoyed mild, almost tropical climates.

During glacial stages those northern plants and animals that were unable to support the cold conditions of the glacial stages either were killed off or migrated to the tropics. Many southern plants and animals moved north during the warm interglacial stages. Smaller plants and animals started to dominate the world.

The "Recent" (Halocene) epoch started about 50,000 years ago when the fourth glacial deposits receded. It is not known whether we are now living during an interglacial period, or if the last receding ice stage inaugurated the beginning of a new, long, mild era of normal geological time.

The sedimentary rocks laid down during the Quaternary period are being explored and studied all over the world by archaeologists and other scientists who are trying to reconstruct the recent evolution of humans, animals, and plants. They have divided the history of this period into several ages. The Paleolithic period or "Old Stone Age" began about a million years ago and witnessed the appearance of the first ancient

primitive humans. These savages were able to use fire and cut stones into rough implements and weapons. They were replaced by the first race of modern man after the receding of the last glacial deposits about 50,000 years ago. These new kinds of humans knew how to make their own fire by friction, and sew, cut, and polish stone into needles and other small smooth tools and weapons. About 20,000 years ago the Neolithic or "New Stone Age" people were able to make pottery, weave, cut, and shape excellent utensils and implements out of bones and horns; they hollowed out logs into boats, started to breed and domesticate plants and animals, and inaugurated religious belief. The "Metal Age" began about 10,000 years ago, during which wheels and sailing ships were invented; the conversion of water, gas, oil, and coal into steam, mechanical, combustion, and electrical power was accomplished; electrical means of communication were discovered; modern means of transportation and the agricultural and other sciences were developed. The "Atomic Age," which probably inaugurated a new industrial era, started in 1945 when the first atomic bomb was tested in New Mexico.

Since the rise of human beings the evolution of many living organisms has been directed to fit the needs of man. Many plants and animals that otherwise would have disappeared have been selected, domesticated, cultivated, and bred by man because they are of value to him. He has changed the natural distribution and number of many plants and animals by moving them from their place of origin to other localities, by increasing their numbers, and by destroying others.

Certain local features of the earth's surface have been changed by man in order to enable him to cultivate plants in areas where they would be unable to establish themselves naturally. Dams and other structures have been built to harness rivers, provide reservoirs, and conduct water to arid lands. The destructive weathering of exposed seashores, mountain slopes, hillsides, fields, and sand dunes has been checked by planting anchoring plants and building terraces and retaining walls, and by other devices. Huge forests have been burned, rocky lands cleared, salty deserts neutralized, and wet places drained to provide additional space for the growth of valuable crops.

A continuous warfare against harmful weeds, injurious animals, and dreaded plant diseases is being waged. Protection against damaging climatic occurrences is given by open-air heating stoves, windbreaks, supports, and various kinds of coverings and shelters. New methods for the preservation of our present crops, the development of new kinds of plants, means for increasing the available space for valuable economic crops, and other important studies are constantly being made. Plant explorers search for new kinds of plants and parasites that attack injurious insects and disease organisms. Experiments of all kinds

are continuously being carried out. New materials and methods are being discovered and tested. When these have proved to be successful, they are published so that everyone may benefit from the new findings. More and more of our earth's surface and its inhabitants are being changed to fit our needs, and climatic factors are being studied so that they too may someday be under the control of man.

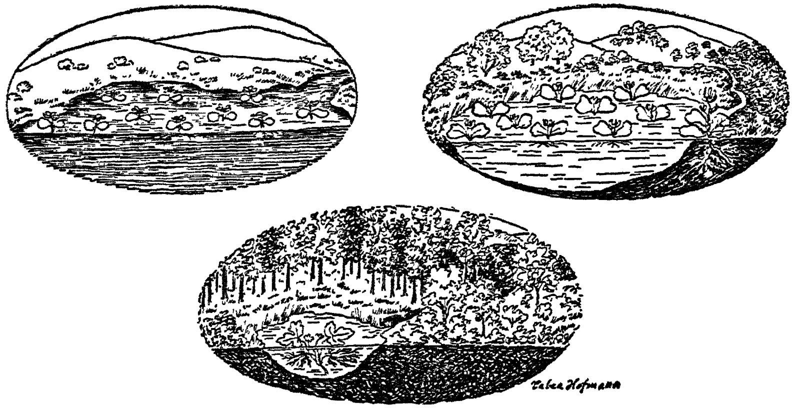

Fig. 79. Change is constant and unrelenting.

20. EVOLUTION

LIVING organisms evolve in several directions as new forms of life appear and older ones remain, develop, or disappear. The plants, animals, and humans living on the earth today are descendants of a long line of ancestors that have succeeded one another, generation by generation, since the remote time when the very first bit of protoplasm was created. We do not know how or where life started, neither do we know in what forms it will exist in future ages. We are now living and witnessing life along several branches of the evolutionary tree of life, somewhere between the moment of creation and its ultimate unknown goal.

Organic evolution is possible because living beings are the products of a continuous uninterrupted stream of ever-changing, ever-growing, and ever-multiplying protoplasm. Through changes taking place in the genes, variations that occur in their combinations in chromosomes, and the continuous modifications that environmental factors such as the earth, its waters, atmosphere, and climates undergo, we have the mechanism for the evolution of all living organisms.

The genes that a living organism receives from its parents are able to exert their influence in controlling the many activities taking place, and permit the hereditary characteristics to appear only when the proper nutrients and working conditions are present. These are supplied by the environment. An apple tree may have the hereditary ability to produce many fruits. But it will not be able to do so if it does

not receive sufficient water, if an insect eats up its leaves, if any environmental condition checks the intake and distribution of necessary nutrients, and if the proper working conditions are disturbed in any way. Each different kind of plant and animal is able to thrive and reproduce itself only in the particular environment that permits its hereditary factors to function properly. A seaweed can grow only in water, a tomato plant is killed by the first fall frost, and a sugar maple must experience a certain amount of cold. A person may have the inherited ability to be a great artist, but if he does not have the necessary peace of mind, paints, brushes, and canvas he will be unable to develop his talent.

The characteristics and growth of an organism, therefore, depend not only upon the genes that it possesses, but also upon the environment in which it is growing. Some genes are more or less independent of the environment, while it strictly limits the work of others. Changes in the environment cause modification in the growth and form of a plant or animal only if the genes it possesses have the ability to adjust themselves to the new conditions. Modification in the habits of growth, structure, and form of an organism may vary according to the strength and duration of the stimulus produced by the environment. The same plant may be tall or short, its roots deep or shallow, its leaves and stems thick or thin, it may flower early in the spring or late in the fall, produce an abundant crop or no fruit at all, depending upon the environmental conditions it experiences. But no organism can adapt itself to environmental conditions more than its genes permit. A dandelion can never be as tall as a sunflower, a pine tree can never have the large flat leaves that grapes possess, and no environmental conditions can induce a wheat plant to produce rye seeds. If the environmental conditions are the same for two orange trees, the one with the best hereditary factors for that particular environment will produce more and better fruit than its neighbor that has a poorer selection of genes. A person without any inherited artistic talent may have a wealth of materials on hand and be unable to draw the likeness of the most simple object.

Variations due to mutations and recombinations of genes during sexual reproduction are constantly taking place. Some are beneficial, others detrimental. The first test that every new organism has to pass, in order to live, is whether it has the proper environmental conditions for its hereditary factors. All those new forms of life that are unable to pass this test never start to develop at all, or are killed before maturing and producing offspring. Every new variation that helps the individual is perpetuated by being passed on to the next generation. Every change that is detrimental forces the death of the plant or animal.

When any change in the environment takes place, those new forms of life that have the ability to withstand the new conditions by modify-

ing their growing habits and structure are the only ones that will survive. Although the genes themselves are not affected by the environmental changes, the organism that contains them is able to modify itself. Its offspring will receive the same genes, and the new generation in turn will be able to modify itself under the same environmental conditions.

Let us see how hereditary factors and environmental conditions may react together by taking for an example ten imaginary plants growing in a pond (Fig. 79). We shall say that each plant lives one year and produces many hundreds of spores before it dies. As there is space and food for ten plants, only ten spores will be able to germinate, grow, and mature into plants every year. The other spores do not have a chance to develop to maturity in this pond. They can develop only if carried away to some other body of water that experiences approximately the same environmental conditions, and where there is sufficient space and food for them. Which ten spores will be chosen by nature to replace the population of the pond will be a matter of luck to only a limited degree. A spore that has been produced sooner, contains more food reserves, and grows quicker has a better chance than the others. In other words, those ten spores that have the best hereditary factors for the environmental conditions of that particular pond will have a head start over all the others, unless any one of them has the misfortune of being eaten by a fish.

If one of the ten original plants happens to produce wrinkled spores that have richer food reserves, and another one has the ability to grow faster, in time, by cross-fertilization and natural selection of the fittest, all the plants in the pond will be the offspring and parents of heavier and quicker-growing wrinkled spores.

A spore from an altogether different kind of water plant may be carried by wind and deposited in the pond. Let us say that this new plant grows taller, has better leaves, and is able to replace one of the ten plants and thrive. If it is able to cross with the offspring of the original plants, there will be, in time, tall, fast-growing, large-leaved plants producing heavy, wrinkled spores. If the new plant is unable to cross with the others or propagate itself, all traces of it will disappear after it dies. If it can propagate itself and is better fitted for the pond, its offspring will replace those of the original kind. Under certain circumstances it may reproduce itself and its offspring grow alongside the others, and the pond will be populated with two different kinds of water plants growing side by side.

Time passes. Generations of plants succeed one another year after year. They will continue to live and retain their characteristics as long as no mutations occur and the environmental conditions remain the same. But nothing in the universe remains stationary. One year ice may form on the pond earlier than usual. If one of the plants happened to

have formed spores before the cold wave descended, all the future offspring in the pond will produce early spores. Some time later a powerful wind may pass and agitate the water into strong waves that tear apart all the plants. If just before this catastrophe took place a mutation occurred in a dividing cell and the fruiting branch that grew from this cell has very tough and resisting tissues, it will be able to withstand the rough treatment. The spores produced by this branch will slowly repopulate the pond with offspring that have the inherited ability to withstand the tearing power of waves.

The stream that renews the water in our pond has been cutting deeper and deeper into the earth. Little by little it is carrying more and more soil particles and depositing them at its mouth, forming a small mound. A mutation may take place in a spore in the form of a new gene having the power of changing a cell into a small rootlike holdfast. This tiny structure has excellent absorbing powers, while the other cells in that plant are unable to take in certain needed salts from the water in the pond. As long as no change occurs in the environment, every spore that produces such growth dies. One day a spore containing such a gene happens to fall right on the small mound of soil. It thrives. The mutation and the changed environment have clicked. The environmental conditions for that special type of growth are excellent. The plant that grows is able to produce spores, and these carry that special gene. Every time such a spore happens to fall on the accumulation of soil, it will prosper. If it happens to land anywhere else it will die. Whenever a spore from the other plants falls on the soil, the resulting plant will be unable to live because it will not have the special absorbing cell needed for the changed conditions. As the collection of genes in the new plants are different, they will not be able to cross, and we shall have two altogether different kinds of plants in our pond, one kind floating, the other fixed in place.

As time passes, more and more soil is deposited in the pond. Many different kinds of mutations and cross-fertilizations will take place. Every time that a variation in any of the plants fits with the changing environment, it will be retained, added to those that have taken place previously, and passed on to the next generation. During the passage of millions of years many different kinds of plants will develop, live for a certain period of time, and in turn be replaced by other types of plants. Some of the spores of the original water plants and of the intermediate forms of vegetation may be carried to other ponds that may not have undergone any changes, or where different kinds of conditions exist and other changes are taking place. The populations in each one of those places may be altogether different.

Many more millions of years have passed. The pond is filled with soil. The present plants do not seem to have any of the characteristics of their

water-plant ancestors. They are land plants. But a few may still retain several genes that can function in water. If a seed from one of these happens to fall into a shallow pond, it will develop into a plant that has both land and water characteristics (Fig. 80). Its roots will be growing in the soil under the water, part of its stem and several leaves will be submerged in the water, some leaves may float on the water, and the rest of its stem and leaves and its flowers and seeds will grow exposed in the open air. The leaves growing in the water will be long and thin, and will resemble the growths of their ancient water-plant ancestors. Those on the water will float and may have water characteristics on their underside and land traits on their upper, exposed surfaces. The exposed leaves will have the more recently acquired land type of structure and form. The plant that grew out of this seed was able to modify its form

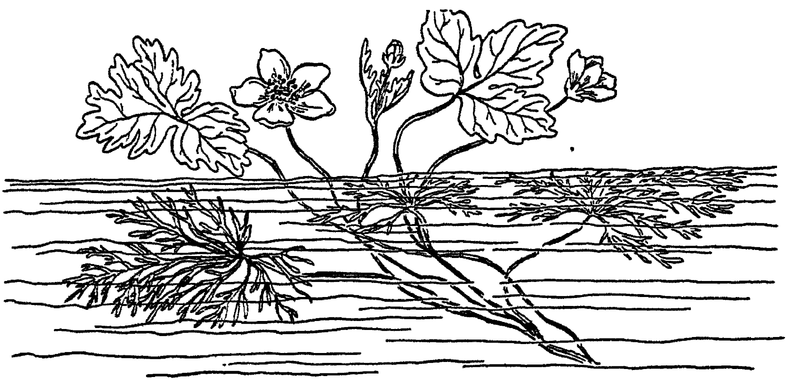

Fig. 80. Water ranunculus

in the changed environment because it contained a collection of genes from its water-growing ancestors. It is able to grow either partly submerged in water or entirely on land. Every time the seeds of this type of vegetation fall in water, the plants produced will modify their leaves accordingly. If a seed that does not contain the proper genes falls into the water, it will not be able to germinate and grow into a plant. Later in evolutionary time the plants may have lost all their water-adaptive genes and be unable to modify themselves properly for a water environment.

All the wonderfully complicated forms of plant, animal, and human life that populate the world today are believed to have evolved from a few simple organisms in probably the same way that the offspring of our ten original imaginary water plants were transformed into land plants.

The total amount of life that our earth can support is limited. When all the conditions for growth are equal, two plants can produce only two offspring that will survive and produce seed in turn. Many more billions of new daughter cells, spores, buds, seeds, eggs, and young are produced each year than can possibly occupy the limited space of the waters, land, and atmosphere of our earth. Under normal circumstances only those offspring that came from parents that had the best hereditary potentialities are able to survive, because, to a large degree, they are able to adapt themselves to many different kinds of environmental conditions by modifying their forms or by other means. Of course, the very best seed falling in a bad locality, or a seed that is crushed by a falling stone, will not have a chance.

Man has been able to select and save those plants and animals that are useful to him by domesticating them. Many of our best plants and animals would have disappeared many hundreds of years ago if he had not propagated and tended them.

As environmental conditions change and new variations of life appear, nature works like a sieve, separating those forms of life that can survive from those that cannot. Only those that change in the right direction are selected to survive and leave offspring; the others are relentlessly killed off. Evolution continues as advantageous variations arise and are perpetuated by being transmitted to offspring, and new changes are added to those already accumulated. Some changes appear suddenly as mutations and hybrids, others gradually by the accumulation of new genes. Some changes may affect one characteristic, others may cause the creation of a completely new form of life. Some changes are in a forward direction and add new complications to those already in existence. Others are in a backward direction causing the loss of one or more characteristics. We believe that many of the fungus growths present on our earth today are a result of modifying mutations that occurred in seaweeds. Some forms of life have remained unchanged for a great many millions of years, others are undergoing rapid changes. Many have been killed off along the way, and the only remains that a few have left behind are imbedded in rock formations as fossils.

The constant changes and selection of the best that take place in nature affect not only the growth habits and structure of individuals, but also the relationships between entirely different kinds of organisms. Some plants obtain sunlight by climbing on others. Many organisms are mutually dependent on one another. Flowers have enticing odors, special foods, and bright colors, which assure cross-fertilization by attracting insects. Animals eat attractive juicy fruits and distribute the seeds. Many forms of life have evolved that live on other kinds of organisms as parasites.

The variations that may occur in any individual may appear to be the

result of a blind mutation, or a hybrid formed by a haphazard combination of chromosomes from two entirely different organisms. But when we consider the phenomenon of evolution as a whole we must conclude that it takes place progressively according to some unknown laws of nature.

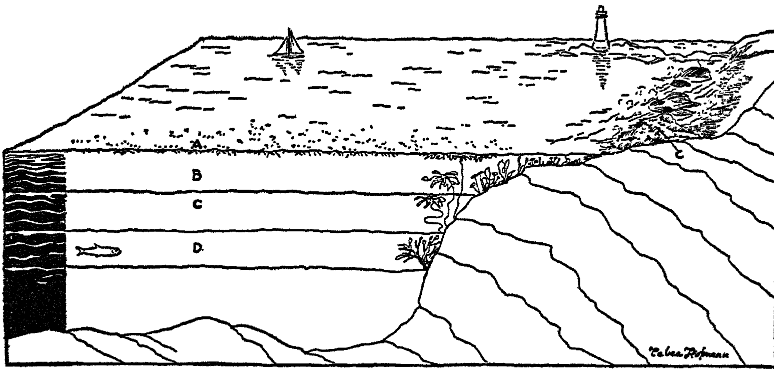

Fig. 81. Algae: (a) plankton, (b) green algae, (c) brown algae, (d) red algae

21. FIRST PLANTS

ALL the lowliest forms of plant life are grouped together under the huge division of Thallophyta, which is derived from Greek and means young plant (Fig. 78). There are many hundreds of thousands of different kinds of thallophytes living in the waters, underground, on moist surfaces, and upon other living and dead organisms all over the world. The natural classification of the many different kinds of thallophytes is very difficult and incomplete because so many intermediate ancestors have completely disappeared without leaving any trace, and those that are living are only very distantly related. The many diverse classes are grouped together into this division chiefly because they all lack true roots, stems, and leaves. The simple structure of this type of vegetation is called a thallus and gives the name to the entire division.

Those thallophytes that have chlorophyll bodies, and are therefore able to manufacture their own food, are called Algae, and form the subdivision of seaweeds and their relatives. The second subdivision is named Fungi, which is an ancient Latin word for mushrooms. They do not possess any chlorophyll bodies, and are unable to manufacture their own food. The Lichenes form the third and last subdivision of thallophytes. These curious forms of vegetation are associations of algae and fungi that grow together.

Many botanists believe that certain living bodies classified as algae and fungi do not belong in the plant kingdom at all. Some of these do not seem to be either plants or animals, others have many characteristics in common to both kingdoms. When these little-known forms of life

are better understood they may someday be grouped together as two or more separate divisions in a new, third, great kingdom of living organisms. Today, enzymes, genes, bacteriophages, viruses, bacteria, and flagellatae are collected and studied by both botanists and zoologists. The protozoa are classified as animals, and the slime molds are grouped within the plant kingdom as a class of fungi.

About three quarters of the earth's surface is covered with water in the form of oceans, seas, bays, lakes, ponds, and streams of all kinds and sizes. These tremendous water areas are very rich in nourishing elements and afford many excellent habitats favoring the establishment and growth of a vast amount and a great variety of life. It has been estimated that about ten tons of new vegetable substances are produced annually in an average acre of sea water. Although many different kinds of bacteria, fungi, and some higher kinds of plants live in these waters, the algae are by far the most important and numerous forms of vegetation present.

There are many different types of water environments. The kinds and concentrations of mineral salts present determine whether a given body of water is fresh, acid, or salty and alkaline. Some forms of plants can live in fresh water only, others prefer alkalinity, still others acidity, while a few algae have no special preference. The amount of light that can be used for the manufacture of food and the pressures experienced are determined by the depth of the waters. The flagellatae and blue-green and green algae live best on the surface of the waters and at very shallow depths near the shores (Fig. 81). The stoneworts and brown algae prefer a submerged existence with a certain amount of water above them. The red algae are able to utilize the very feeble amount of light that penetrates great depths. Those plants that live where great ocean currents exert a certain amount of force, others that are swayed and moved about by strong waves, and the brown seaweeds that are covered and uncovered by changing tides have strong tissues enabling them to withstand rough treatment without being torn into shreds.

Many different kinds of interchanges of materials between the sea, land, and atmosphere are continuously taking place. A body of water that is supplied with many materials by streams that have drained rich lands has a greater amount of life than one replenished by a river that has passed through poorer land. There are more individuals in temperate and cold northern seas than in the tropics, which are, however, stocked with a greater variety of plant and animal life.

The different kinds of algae have adapted themselves so well to their individual environments that specialists can often tell from what body of water a certain organism was removed. They range from microscopic single-celled organisms through many different types of colonial associations, various simple and branched filaments made up of attached rows

of cells, to very complicated huge growths that may be larger than many trees. As the algae exhibit so many different stages in the evolution of the plant body, they are of great interest to botanists.

The free floating and swimming algae, together with the marine animal eggs and young, constitute the plankton of the seas (Fig. 81-A). These ever moving masses of plankton are the main source of food sustaining the enormous number of fish and other types of marine animal life. There is no part of the seas and oceans where plankton organisms do not exist. Even the most transparent-looking sea water contains appreciable numbers of these microscopic plants and animals. The seaweeds and various animals that are fixed in place by strong holdfasts make up the benthonic population of the waters.

The algae contain a greater variety of salts than any other plants and are very rich in carbohydrates, vitamins, and various other substances. They are the original source of food for all of the marine animal population. Many Asiatic and other peoples use over seventy different kinds of algae as one of their main foods. We extract gelatins, iodines, and various drugs from different algae, and they furnish us with many other valuable products such as diatomaceous earths and fertilizers that are very rich in potash.

Blue-Green Algae

The most primitive true plants are the blue-green algae (Cyanophyceae) (Fig. 82). This class name reflects the fact that some genera have many blue pigments that mask the green chlorophyll bodies. A more fitting term for these very colorful simple organisms would be rainbow algae, because many kinds have brilliant red, green, yellow, and various other hues. One species of this red-pigmented algae that lives in the Red Sea gives that body of water its characteristic color.

Algae are all very tiny plants, 1/25,000 of an inch long, consisting of simple single cells that have no regular definite nucleus or chloroplasts. In most species the cells cling together in small threadlike filaments; the bodies of others are made up of clusters or sheets of cells. One genus, the Nostoc, resembles small pieces of colored putty (Fig. 82-D). Each colonial organism is about a quarter of an inch in diameter and consists of hundreds of filaments that are held together by a gummy and sticky substance.

The blue-green algae can live in both fresh and salt water. Many thrive in hot springs at higher temperatures than any other plants; others enjoy extremely low temperatures and live in ice and snow. They are also found as slimy growths on mud, sand, dripping rocks, stones, and wood. Some species live underground in the soil. Sometimes a great number of water-growing species are present in stagnant waters, where they form the familiar dirty, smelly "bloom" that is poisonous to

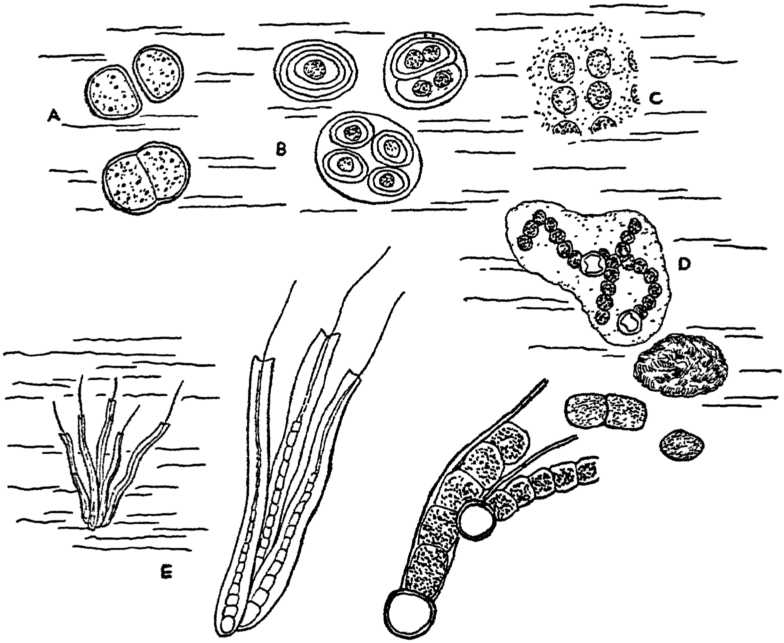

Fig. 82. Blue-green algae: (a) synechococcus, (b) water bloom, (c) merismopedia, (d) falling star (nostoc), (e) rivularia

land animals and humans. A certain water genus (Oscillatoria) has thin strands of filaments that sway and move their tips slowly around in a rotating motion.

When unfavorable conditions for growth appear, any single cell of a filament may form a hard covering and resemble a spore, which can rest until conditions for growth are favorable again. The blue-green algae are often classified into a group with bacteria, because both these types of organisms resemble each other in some ways, and reproduce themselves by simple fission. Some kinds of these algae, though, can form asexual spores, which the bacteria are unable to do. The blue-green algae are among the very few kinds of plants that have lasted unchanged for many geological periods. The earliest recognizable plant fossils found so far are the direct, similar ancestors of these present-day plants. It is estimated that some of those fossils are about a billion years old.

Green Algae

The green algae (Chlorophyceae) form the largest of all classes of algae, and are divided into many groups the relationships of which are

not as yet well understood. The cells of all the organisms in this class have a definite nucleus and one or more green chloroplasts. They exist in all forms from single-celled organisms to branched filaments. Some species float on the surface of waters, others swim, and certain kinds are anchored by holdfasts to ocean bottoms and various damp exposed surfaces (Fig. 81).

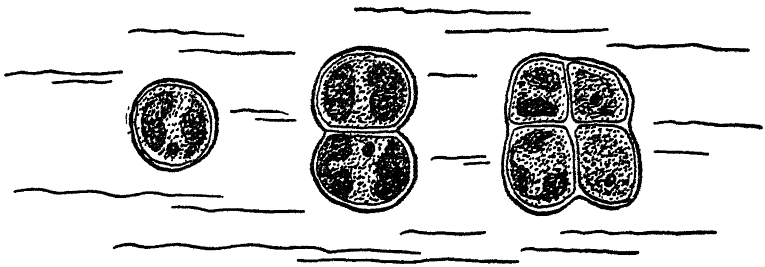

Fig. 83. Flowers of the sea—Protococcus

The simplest and most widely spread green plants in the world are the flowers of the sea (Protococcus) (Fig. 83) which form the green coating on damp and shady branches and trunks of trees, rocks, fences, and similar objects. The entire organism consists of very simple cells that exist either separately or attached together in groups of two, four or more.

FLAGELLATES

One of the most advanced groups of single-celled organisms are the Flagellatae (Fig. 84). These are among the borderline organisms between the plant and animal kingdoms. It is probable that the plants

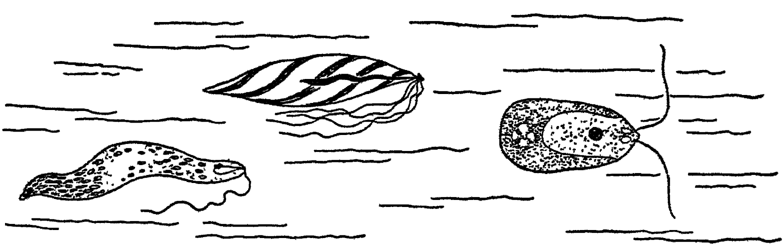

Fig. 84. Swimming algae (Flagellatae)

and animals living today have evolved from such dual life forms. Some of the genera in this class are classified as animals, others as plants. These organisms are able to move about in the waters in which they live by using threadlike tails called flagella. One of the plant types called

Chlamydomonas (Fig. 38-B) lives in ditches, pools, lakes, and on moist soil. It is shaped like an egg, microscopic in size, has a firm cell wall made of cellulose, a clearly distinct nucleus, a large prominent plastid containing chlorophyll, several specialized enzymes, and two small vacuoles that constantly expand and contract as food is being manufactured, processed, stored, changed back to soluble forms, and used. The most remarkable feature of these small organisms is that they have a tiny orange pigment that is very sensitive to light. By the use of this eyelike spot the plant is able to detect light and swim from a dark place toward sunshine. It is also sensitive to great illumination, and will move away from too bright light and swim toward a darker place. When the locality in which these organisms live dries out, they can change into a resting spore state until the right conditions for growth return again. While in a spore state they can be lifted and moved great distances by winds. One kind of flagellate is red and lives in very cold climes. It is this genus that produces the phenomenon known as "red snow" in northern lands.

While the cell is actively swimming or when it is in a spore stage it may divide itself into two or more daughter cells, which develop their own flagella before they leave the mother cell. These organisms exhibit the most primitive stage of sexual reproduction when the mother cell

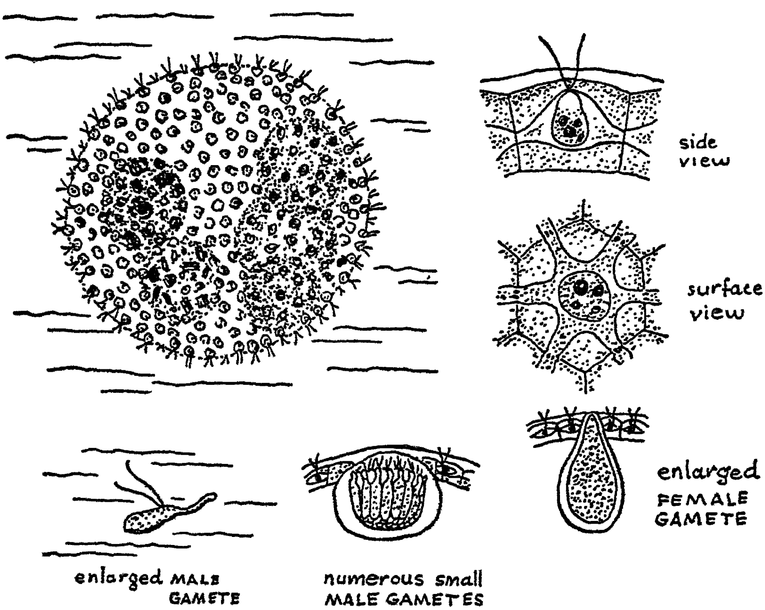

Fig. 85. Water sphere (Volvox)

divides itself into eight small gametes, which swim about and fuse together to form mobile zygotes. These fertilized cells at first have two eye spots and four flagella, but soon come to rest and are changed into single-eyed normal swimming cells. The two gametes may come from the same mother cell, from two cells of the same plant, or from two different plants.

Some flagellates, such as the Volvox (Fig. 85), have a tendency to rest united together temporarily and form hollow spherical colonies. Each colony may contain anywhere from several hundred to forty thousand or more independent swimming cells and be as large as a pinhead. The individual members of such colonies form large female and small male gametes. The female gametes sometimes assemble within the sphere, and when they are fertilized leave their parent colony as a group to start a new colony.

Pond Scum

The Conjugatae are a large class of single-celled, colonial or filamentous plants that float in fresh waters and reproduce themselves by simple conjugation. The two most interesting groups within this category are pond scums and the beautiful desmids.

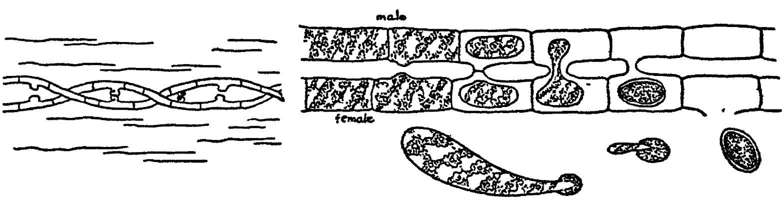

Fig. 86. Pond scum (Spirogyra)

The Spirogyra are one of the most common pond scums (Fig. 86). In this genus the chlorophyll bodies are arranged as broad spiral bands encircling each cell. The nucleus is suspended in the middle of the cell by strands of cytoplasm. The filaments are often covered with a gummy substance that makes them very slimy. They sometimes propagate themselves by fragmentation, when a single cell or a group of cells detaches itself and grows into separate individuals. More often they reproduce themselves by simple conjugation, when the contents of one cell move through a tubelike extension to fuse with another.

Desmids

One of the most beautiful living organisms in the world is the desmid (Fig. 87). Desmids are single-celled or colonial structures that live in acid peat moors and in rancid fresh waters. They are often very narrow

in the middle, and some kinds look as if two or more like individuals were attached together. There are over a thousand species of desmids of many different shapes and sizes. The walls of most of these graceful

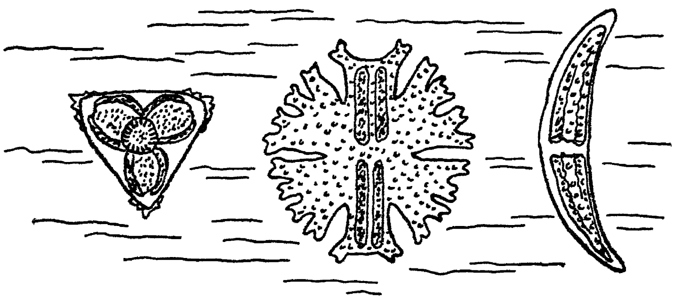

Fig. 87. Desmids

plants are covered with variously shaped spines and hairs, and they are often perforated with differently shaped holes. The desmids reproduce themselves by typical cell division and conjugation.

Diatoms

Another large group of very interesting single-celled algae are the diatoms (Bacillariales), sometimes classified as golden-brown algae (Chrysophyta) (Fig. 88). There are more than fifteen thousand known

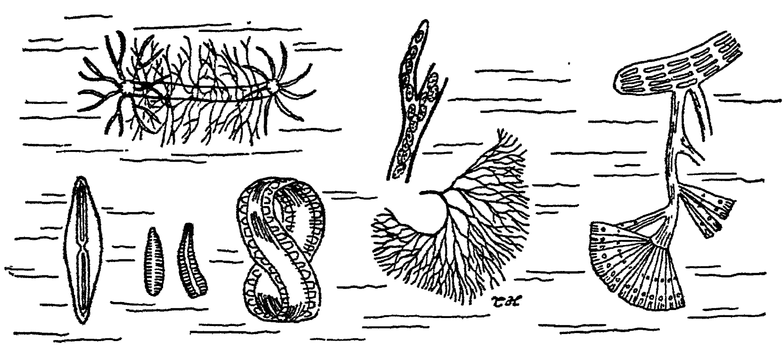

Fig. 88. Diatoms

species of these curious organisms, most of which are of yellow and brown color. They live in both salt and fresh waters, on many water plants, and in moist and cultivated soils. They prefer cold climates and are most abundant in antarctic waters. Most species are covered with two separate walls or valves made up of heavy layers of silicates that

overlap one another and fit together in much the same way as the two halves of a shoebox. Some are circular discs, others are boatshaped. The valves are often ornamented with numerous fine markings that are so mathematically exact in their symmetry that the lenses of microscopes are tested by examining them. Although they do not have flagella some diatoms are able to move in the water by the use of a mechanism that is not well understood.

Diatoms reproduce themselves by typical cell division (Fig. 89). This process takes place when the protoplasmic content of a mature diatom reaches a certain maximum volume and pushes the two hard

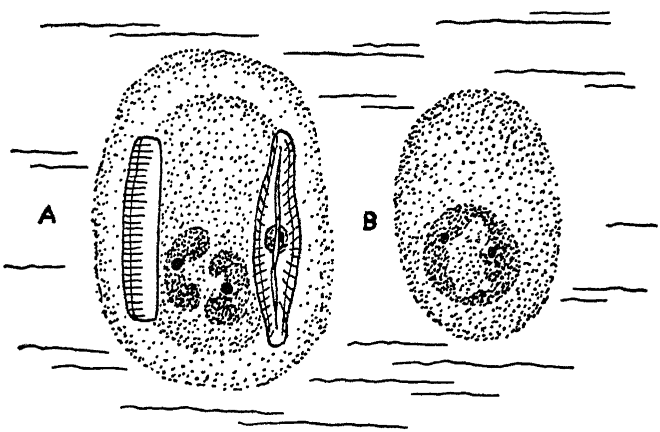

Fig. 89. Sexual reproduction of diatoms: (a) two neighboring adult diatoms leave their valves, (b) their protoplasms fuse.

walls apart. On separating, each daughter cell receives one of the two valves and forms a new wall on its naked side, which fits into the old one. The new valve will necessarily be smaller than the one it received from its parent. In every successive division there will be a reduction in size of one daughter cell until such a small diatom will eventually result that it will be unable to function properly. When such a minimum size is reached, the protoplasmic content leaves its walls and fuses with the liberated contents of an adjoining diatom, and the new, large naked mass of protoplasm will grow and eventually form two new cell walls and start a new cycle.

Since the hard silicate walls are practically imperishable, enormous deposits of diatom fossils have been found in many places. Millions of square miles of sea bottom are covered by the dead shells of ancient diatoms. They are also found on land that was covered by seas in former geological ages. Some land deposits, especially in Bohemia, California,

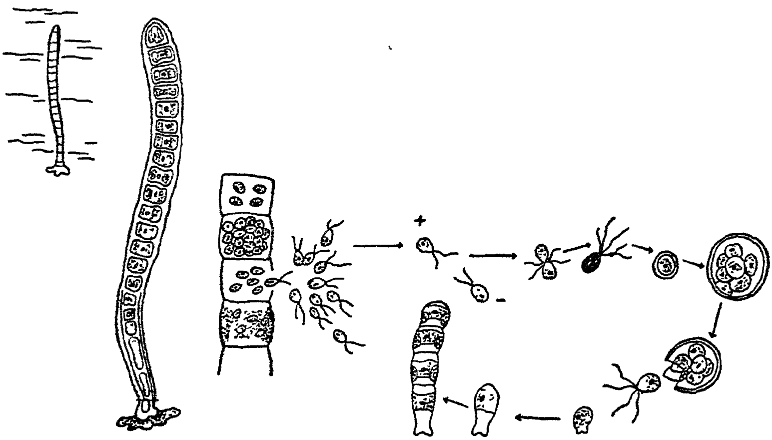

Fig. 90. Sexual reproduction of sea lettuce (Ulothrix)

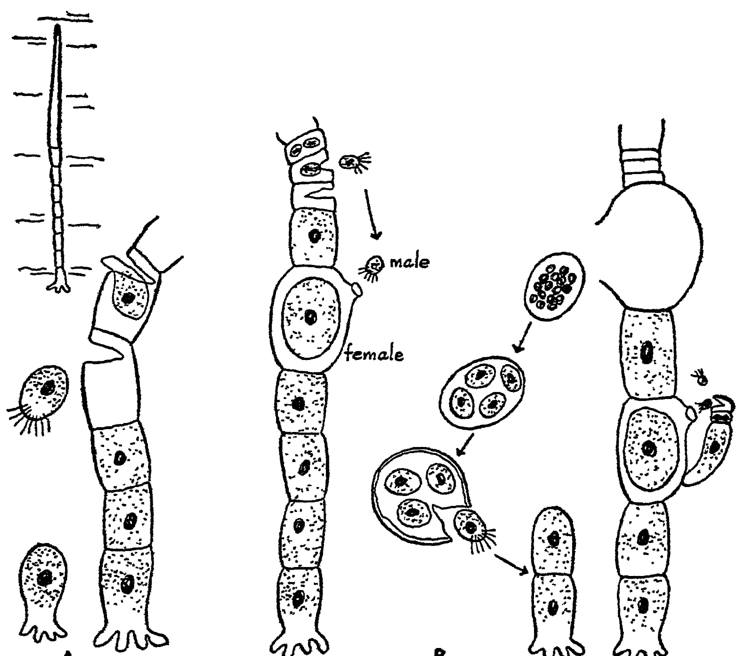

Fig. 91. Life cycle of Oedogonium: (a) asexual reproduction, (b) sexual reproduction

Virginia, and Wales, are over three hundred feet deep. These deposits are harvested and the gray and white diatomaceous earths are used as filters in sugar refineries, in polishing powders, in tooth pastes and powders, in the manufacture of dynamite, and for many other purposes. The water diatoms are the most abundant constituents of the vegetable part of plankton.

Sea Lettuce

The Ulothrix is a very simple single-stemmed or unbranched seaweed that has a holdfast at its lower end (Fig. 90). The majority of these live in fresh and salt water, but some kinds are able to grow on stones, and on trunks, branches, and leaves of trees in the moist tropics. This type of growth shows the beginnings of a multicellular type of vegetation as distinguished from single-celled or colonial forms of growth. The Ulothrix reproduce asexually by forming swimming spores that have four flagella, and sexually by gametes that have only two flagella. When the swimming gametes fuse, the egg cell has four flagella and resembles a swimming spore. When germination of the spore starts to take place, the tails are absorbed and growth by cell division takes place. The sea lettuce or green laver, which is closely related to Ulothrix, is used in Iceland, Ireland, and Scotland as a food.

Oedogonium

A very much higher form of green algae that shows the beginnings of cell specialization is seen in the Oedogonium (Fig. 91). This is a filamentous seaweed that lives attached to submerged objects in shallow waters. Only certain cells are able to divide and add new growth to the plant body, while other structures specialize in the formation of definite male and female gametes. The female gametes are large, stationary, and have food reserves, while the male gametes are small and swim to the cell that contains the female gamete.

Green Felt

There are many kinds of tubular green algae (Siphonales) (Fig. 92). The entire plant body of these kinds of plants is a huge single cell about an inch and a half high without any cross walls or divisions. The mass of cytoplasm in which thousands of nuclei are imbedded circulates within the plant. The green felt (Vaucheria) is a very common tubular green algae that reproduces itself by both sexual and asexual means. The gametes are formed in highly specialized structures.

Coleochaete

The most complicated and highly specialized green algae are the Coleochaete (Fig. 93). The vegetable body of these plants consists of

a flat plate or cushion of radiating or branched filaments. Each filament forms distinct vegetative spore cases and specialized sexual fruiting bodies. This is one of the earliest plants known that retains its female gametes and fertilized egg cell. After the egg cell has been fertilized, the zygote divides into eight spores, which are then released. Some botanists believe that these are the direct ancestors of the mosses.

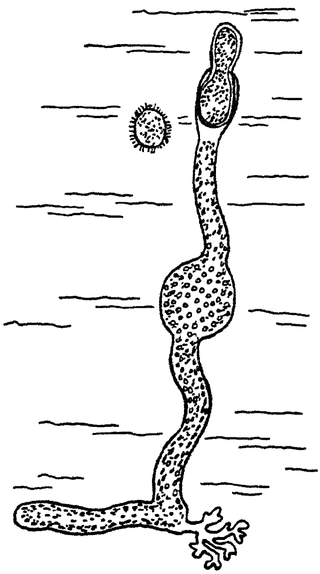

Fig. 92. Asexual reproduction of green felt (Vaucheria)

Stonewort

The relationship of the stoneworts (Characeae) to other types of vegetation has not been established (Fig. 94). Most botanists consider these plants to be green algae because they are green and live submerged in ponds and ditches, where they form dense prairies of underwater vegetation. The plants grow to be a foot or more high and are made up of joined stalks from which short whorls of branches arise at special joints. These plants do not form any asexual spores. Their sexual reproductive organs are among the most complicated of all thallophytes. In some species both male and female structures are on the same individual, in others they are found on separate plants.

Brown Algae

The largest underwater plants that also display the highest degree of specialization in their body cells are the brown algae (Phaeophyceae) (Figs. 81, 95, 96, 97). Their chlorophyll bodies are masked by the yellow and brown pigments that give them their characteristic colors. These plants seem to represent a separate type of vegetation that did not evolve directly from the flagellates or green algae, but from some unknown ancestors. As far as is known, no higher forms of plant life have evolved from any species in this class. They live attached to rocks along shallow seashores, where they are often exposed to the air several hours daily because of tidal movements. Some live submerged up to depths of fifty feet along border zones. The broad, flattened, leaflike blades of many kinds have air bladders that enable their upper portions to float. When such parts are torn off by actions of waves, strong winds, or tides, they form large floating colonies such as the famous enormous

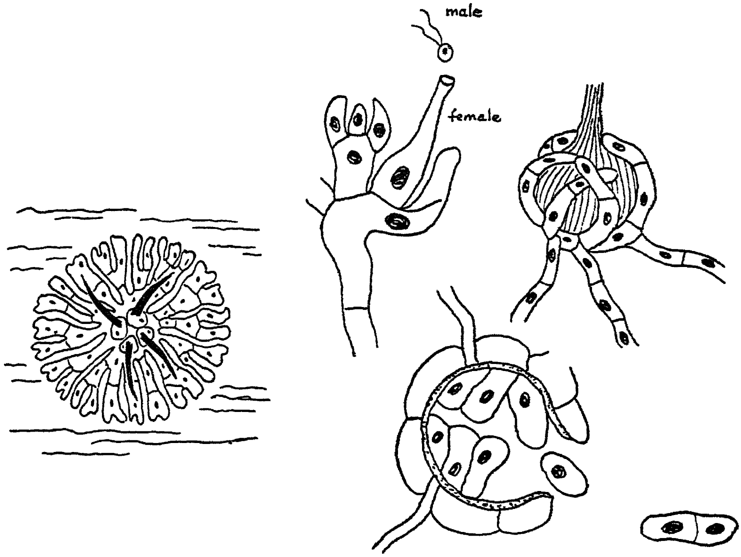

Fig. 93. Sexual reproduction of Coleochaete

areas of floating gulfweeds (Sargassum) that form the Sargasso Sea in the South Atlantic, and other floating accumulations in many parts of the Pacific and other seas.

One of the smallest and simplest kinds of brown algae are the mermaid's tresses (Ectocarpus) (Fig. 95). These plants grow to be one to

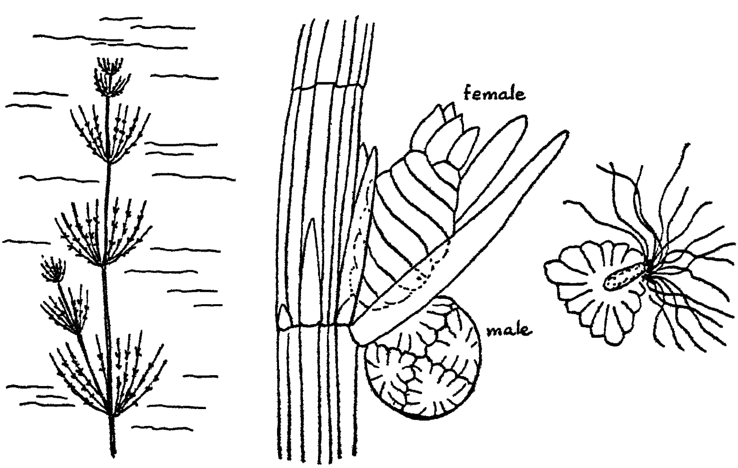

Fig. 94. Stonewort (Chara)

four feet high and are made up of highly branched delicate filaments that form tufts or tresses of vegetation. They reproduce themselves asexually by forming swimming spores in special single-celled structures. The sexual reproductive cycle shows signs of complications, the gametes being formed in multicellular organs on special branches. In some species the gametes resemble the swimming spores, in others there is a difference between the larger, slow-moving female gametes and the smaller, fast-swimming male gametes.

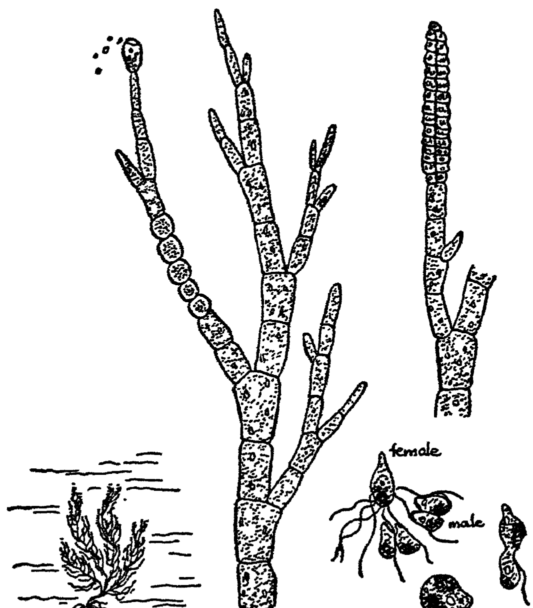

Fig. 95. Sexual reproduction of mermaid's tresses (Ectocarpus)

The Laminariales is a large group of brown seaweeds including the kelps, sea palms, and other related growths (Fig. 96). Many form large beds of seaweeds along the coasts of the Pacific Ocean. The kelps were one of our most important sources of iodine. Many are used as food, and some very sweet kelps are eaten as candy. The body of a typical kelp is made up of millions of cells, only a few of which are in direct contact with the sea water. The thallus shows the beginnings of a marked division of labor among the cells, and is composed of three distinct regions. The holdfast is very branched and anchors the plant so strongly to rocks and other objects that powerful movements of the waters sometimes

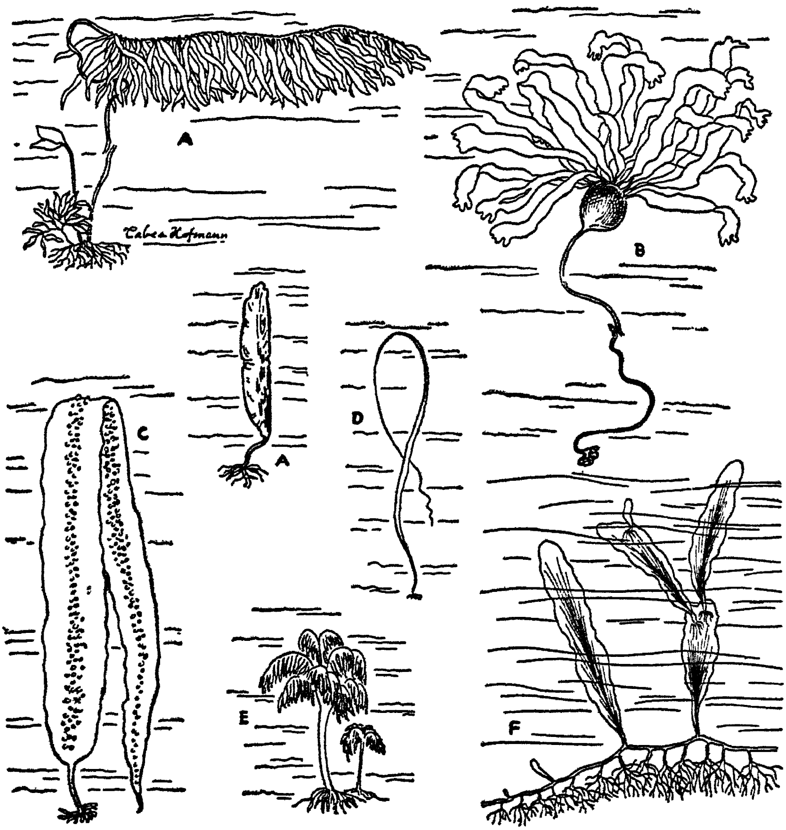

Fig. 96. Brown algae—kelps: (a) giant kelp, (b) sea-otter's cabbage, (c) common kelp, (d) devil's shoestring, (e) lessonia, (f) caulerpa

lift the entire plant with the attached stone, which rises to the surface and floats away. The stout, cylindrical, stemlike stalk may be over a foot thick and several hundred feet long. The outer cells form a protective gummy covering, and the inner ones are elongated and able to conduct a small amount of water and other materials from place to place. The growth of the stalk in diameter is due to the activity of special dividing cells located near the outer skin. At the tip of the stalk another layer of dividing cells grows into long leaflike blades containing the chlorophyll bodies. These blades are covered with a thick leathery layer that protects the inner cells from drying out when the blades are exposed to the air during low tides.

The sea-otter's-cabbage (Nereocystis) has a stem from fifty to over

a hundred feet long, at the top of which is a large hollow ball that floats on the surface of the waters and supports the long thin blades (Fig. 96-B). A very high potash content makes this kelp a very valuable fertilizer. The Alaria, one of the most massive of marine plants, furnishes the murlins used as foods by people in Scotland, Ireland, and Iceland. It has one large very long blade and a cluster of smaller ones at its base. The most resistant underwater plant is the sea palm (Postelsia), which grows to be about two feet high on rocks along rough tidal coasts. Its thick tough stalk and very thin strands of leaflike attachments are able to withstand the most punishing treatments. The giant kelps (Macrosystis) (Fig. 96-A) may reach lengths of three hundred or more feet and are said to be the largest living things in the world. The commonest kelp is the Laminaria (Fig. 96-C), which gives the entire group its name. The long flexible stalk terminates with a broad flattened blade. It is a very tough and leathery seaweed of a yellow-brown color. This kelp reproduces itself only by sexual means. The swimming spores do not grow into new plants that resemble the parent. They germinate into very tiny male and female sexual plants. These in turn produce male and female gametes that later fuse to form fertilized eggs, which germinate and grow into the familiar kelp plants.

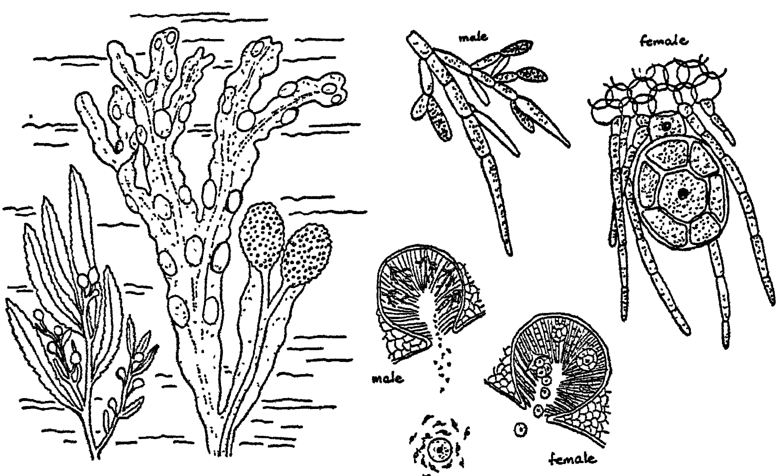

Fig. 97. Rockweeds (Fucales)

The rockweeds, which are sometimes known as bladder wracks, and their relatives are members of the Fucales or Fucus group of brown algae (Fig. 97). They are among the most widely distributed seaweeds in the world. The Fucales have strong branching holdfasts that anchor

them strongly to rocks, stones, shells, timber, and other objects lying along the shores of many seas. The olive-brown growths are very much branched and have a great many swollen air bladders. They reproduce themselves only by sexual means. The reproductive organs are found on enlarged tips of branches, where they appear as tiny sunken cavities. These small pockets sometimes contain both male and female gamete-producing germ cells. The two kinds of structures may be in separate cavities on the same plant, and some plants produce only male gametes, while others produce only female gametes. Each female-producing germ cell usually forms eight large, nonswimming female gametes that are released into the ocean. The male-producing organs form thousands of tiny swimming male gametes, one of which fertilizes a female gamete. The fertilized egg develops into a new bladder-wrack plant.

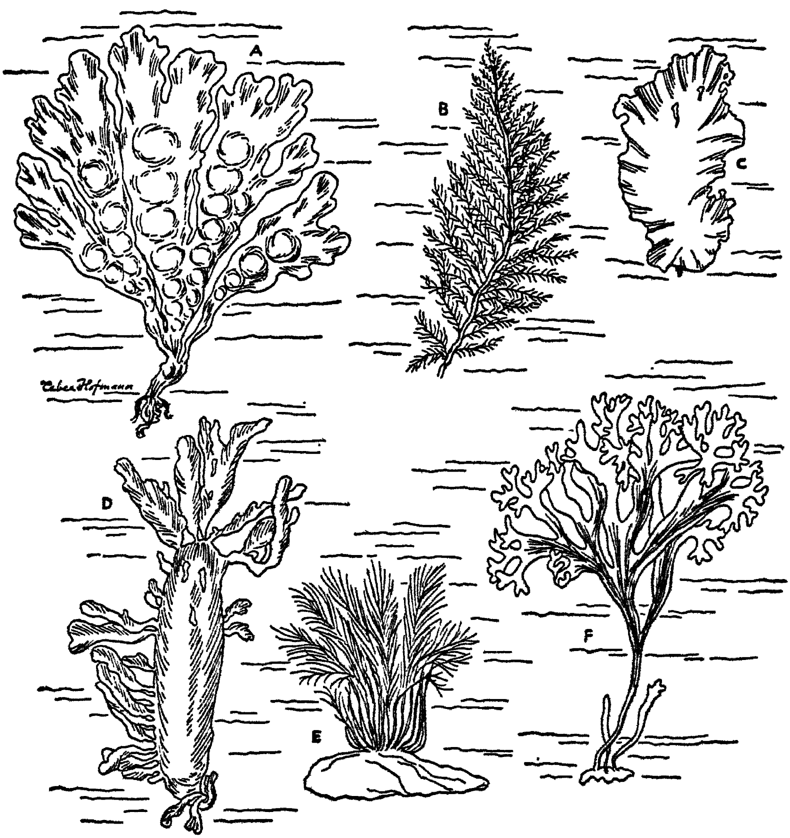

Fig. 98. Red algae: (a) halymebia, (b) spacrococcus, (c) laver, (d) dulse, (e) carolina, (f) Irish moss

Red Algae

The most beautiful and also the most economically important seaweeds are the red algae (Rhodophyceae or Florideae) (Fig. 98). They are of red, violet, lavender, brick, reddish-brown, and other colors. The few species that live in fresh waters usually have a bluish tinge. The cell walls are often so thickly covered with gummy gelatins that the entire plant seems to be imbedded in jelly. Many live in tropical oceans at depths up to about seven hundred feet, and do not grow to be much more than a foot high (Fig. 81). They reach their most luxurious growths in polar seas, where they may attain lengths of five or more feet. There are a great many kinds of red seaweeds, and they show a large variety of forms of growth, complexity of body, and reproductive structures. There are only a few simple types of these seaweeds. Most species seem to have evolved from several higher forms of green algae. None have evolved into higher land types.

The pink laver (Porphyra) is one of the simplest red algae (Fig. 98-C). It is made up of very thin fragile tissues, and resembles the green laver in form and structure. It was used as a purple dye in ancient days, and today is an esteemed food that is widely used in many countries, and is cultivated in China.

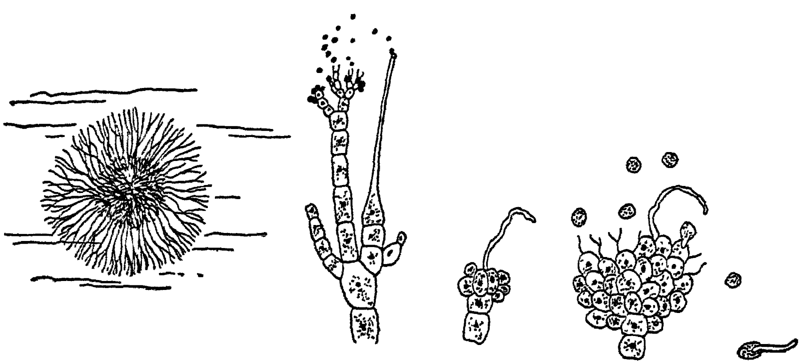

Fig. 99. Sexual reproduction of threadweed (Nemalion)

The threadweeds (Nemalion) are among the best-known red seaweeds (Fig. 99). They are usually of brown or dark purple color. Most species live in salty ocean depths. Each one of the many thickly branched, strong gelatinous threads of a typical Nemalion plant is composed of a dense assemblage of thin filaments. Most threadweeds reproduce themselves by sexual means only.

Agar, which is a very pure form of mucilage-like substance, is obtained from several different kinds of red seaweeds, especially from Ge-

lidium plants. It is widely used in medicines, in preparation of jellies, soups, and gelatinous desserts, and in the paper and silk industries. Agar is a very important medium in which bacteria and other low organisms are grown in experiment stations and hospitals. Many red algae, especially Corallina, extract calcium from sea water, and some grow into huge formations resembling coral reefs (Fig. 98-E). The Rhodymenia, which gives the entire class its name, is a flat, very tough seaweed that is found in the northern Atlantic Ocean and as far south as the Mediterranean (Fig. 98-D). It furnishes the dulse or sea kale of commerce, which is a common food to many people living in Iceland, Norway, Scotland, and Ireland. It is also used as a chewing gum. One of the most important red seaweeds is the Irish moss (Fig. 98-F), which grows along the North Atlantic coast lines. This plant is very rich in gelatinous materials and is used in curing leather and processing cloth, and as an important ingredient of gelatinous desserts, cosmetics, soaps, and pastes of all kinds. Dilsea, which is a flattened leaflike red seaweed, was a source of cosmetic rouge in ancient Greece and Rome.

It is believed that the algae have retained their primitive characteristics down through the ages because they live in an environment that has remained more or less stable for many millions of years.

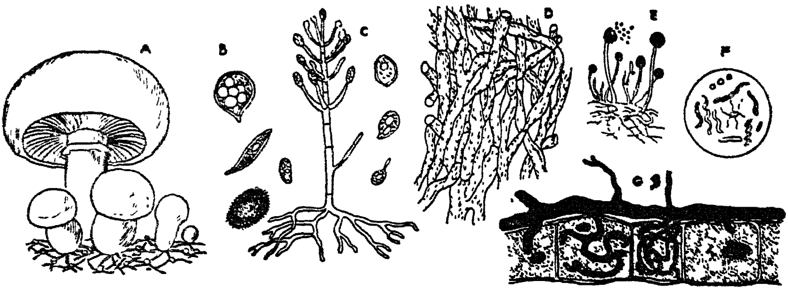

Fig. 100. Fungi: (a) field mushroom, (b) mushroom spores, (c) stripe blight of barley, (d) boletus tissue, (e) black mold, (f) bacteria, (g) downy mildew penetrating tissues of host

22. ROBBERS AND SCAVENGERS

ALL the low forms of plant life that do not possess chlorophyll bodies are grouped together as members of the second subdivision of Thallophyta called Fungi (Fig. 78). Although most fungi are unable to manufacture their own food, practically all are classified as plants because, unlike animals, which take in various kinds of unconverted foods and digest them within their bodies, they absorb substances in water-soluble form only. They prepare their food by releasing special enzymes that dissolve the materials outside of their bodies. Other low organisms are classified as fungi because they have reproductive structures that are found only in the plant kingdom.

About two hundred thousand species of fungi have so far been recognized, named, and classified. They range in size from microscopic bacteria to giant puff balls that are more than a foot in diameter and weigh over twenty pounds. It is believed that a great many new kinds will eventually be discovered growing in the tropics and other formerly inaccessible places. The fungi do not constitute a natural group, but among them are included certain genera that are related more closely to plants classified in other groups than they are to each other. The ancestors of some fungi probably did not have chlorophyll pigments, many are mutated forms of various algae that have lost their green plastids during the course of evolution, and the relationships of others are still unknown.

The primitive plant body, or thallus, may be a single cell, a mass of naked protoplasm having thousands of nuclei, or composed of one or

more thin, usually branched, tubelike threads or filaments. Each filament is known as a hypha, and the whole mass of hyphae, which are often tangled or matted together, is called a mycelium (Fig. 100-D). Some have special absorbing strands through which they draw their food from the material in which they live.

Fungi grow wherever there is sufficient food, water, air, and proper working conditions. Many live in dark places only, others in the light, and some thrive in both strong illumination and darkness. They live on the surface and inside of other living and dead organisms, in the air, waters, and earth.

Many fungi derive some or all of their nourishment from other living organisms and are either complete or partial parasites. They are so numerous that every human being, animal, and plant, wild or domesticated, has a few or many fungi that prey upon it. They are responsible for many diseases, and the loss caused by them is immense. During the course of history countless persons have been forced to leave their homelands and entire civilizations have disappeared because of the famines caused by loss of crops that parasitic fungi have attacked. The many plagues that have appeared from time to time have killed off large percentages of the populations of many countries.

Although many parasitic fungi are responsible for the devastation of tremendous areas of vegetation and the death of millions of people, some do no harm, and a few species benefit the host on which they live.

The saprophytes, or partial parasites, break down organic materials and cause their decay. They are absolutely indispensable for the continuous succession of life on this earth. They release the elements that were locked up as new cells were being formed and growth was taking place, and free them into the air, soil, and water. These liberated elements become available for use again in the building of new life forms. Without saprophytes, carbon and most of the other elements necessary for life would remain locked up in dead organisms and the world would be a lifeless planet.

Many saprophytes have been domesticated, and their activities are controlled by man for his own use. All the fermentations of plant and animal products and innumerable other vital processes are due to the work performed by saprophytic fungi. There are many mutual-benefit associations between these organisms and green plants.

Fungi are not the only robbers and scavengers living on the earth. A few higher plants such as dodder (Cuscuta) and mistletoe (Phoradendron) and all animals are parasites, saprophytes, or both. Some fungi and other living organisms start their life cycles as parasites and continue the process of decay as saprophytes after the host on which they live has been killed by their activities, or when death results by the actions of other factors.

Bacteria

The most abundant and widely distributed plants are the bacteria, which is a Latin word meaning little sticks (Fig. 101). Some authorities differ as to the proper placement of bacteria in the classification of living organisms because the simplest kinds derive their energy from inorganic elements, most are parasites, saprophytes, or both, and a few have red- or purple-colored chlorophyll pigments that enable them to manufacture some or all of their food themselves. Bacteria are usually grouped into four classes, depending upon their shapes. There are

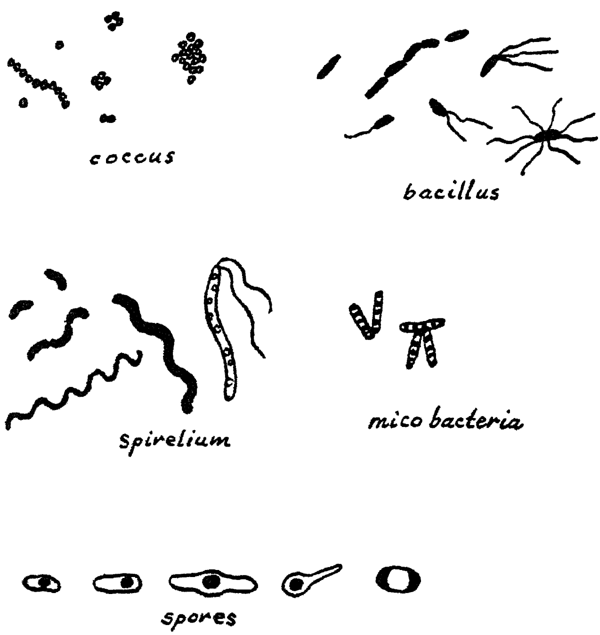

Fig. 101. Bacteria

spherical bacteria (Coccus), rodlike sticks with or without swimming *tails* (Bacillus), moving twisting spirals like corkscrews (Spirillum), and branched bacteria (Mycobacterium). It is not known whether they had a single common ancestor or several different ancestors. Bacteria are classified as fungi because practically all fit the descriptions pertaining to nonchlorophyll thallophytes. Some botanists group the bacteria together with blue-green algae into a separate subdivision they call Schizophyta, Schizomycetes, or fission thallophytes.

Bacteria are exceedingly tiny single-celled organisms, the smallest

being only 1/250,000 of an inch in diameter, and the largest not more than 1/250 of an inch long. Most live as single-celled individuals, while others attach themselves to form colonies resembling bunches of grapes, threadlike filaments, or round discs and spheres. They have no definite inner structure, and their nuclear bodies are scattered within the cytoplasm. Some have pigments and are highly colored, others are colorless. Most are like other living organisms and release and use the energy locked up in organic materials, others are unique in that they are able to oxidize iron, sulphur, and nitrogenous and other inorganic substances. Many use the oxygen of the air for respiration, while some have the ability to extract the oxygen they need from the materials on which they feed.

We all have direct or indirect contact with bacteria, because they live everywhere. Some species are able to live in many different environments, others are strictly localized in their requirements. They are found inside and on the surface of other organisms, on the products of living beings, in the air, waters, and soil of the earth. They live in glaciers and hot springs, in mines and ocean depths many hundreds of feet deep, and at heights of several miles in the atmosphere.

Many form thick protective walls around themselves and resemble vegetative spores when unfavorable conditions for growth arise (Fig. 101). These spores are spread by air currents and can withstand great extremes in environmental conditions for long periods of time. When conditions for growth are favorable, a spore germinates into a single bacterium that reproduces itself by simple fission like the blue-green algae. Under favorable conditions some species of bacteria are able to divide themselves two or three times an hour. It has been estimated that in a period of twenty-four hours a single bacterium could give rise to almost a hundred billion bacteria that would weigh about 25,000 tons if the conditions for growth were perfect and enough food and space were present. Fortunately these organisms are unable to spread so rapidly because of lack of food, and because the organic waste materials that they produce are poisonous to them.

Many bacteria cause diseases in plants, animals, and humans. The most common bacterial diseases of man are diphtheria, leprosy, tetanus, tuberculosis, and typhoid fever. They cause wilting, galls, fire blight of pears and apples, black rot of cabbage, and many other disorders in plants. Although ways have been found to combat most of the bacterial diseases of humans and animals, we are unable to stop their activities in plants without destroying the entire plant.

Some parasitic bacteria that are found in the mouth and inner organs of humans and animals are very beneficial. They elaborate vital vitamins, and are necessary in the digestion of foods. A great many saprophytic bacteria are very useful to man in fermenting wines, liquors,

brandies, cider, vinegar, sauerkraut, silage, and many other products. Special kinds are used in the manufacture of butter and cheese. They separate the fibers in flax plants during the processing of linen. Bacteria are also used in tanning leather, curing tea, tobacco, and vanilla, flavoring coffee, and in innumerable other processes that are important to our modern day-to-day life. The nitrogenous and other bacteria of the soil are especially important in the many processes that take place during the breaking down of organic materials and the building up of chemical solutions into an available form for the use of plants.

Slime Molds

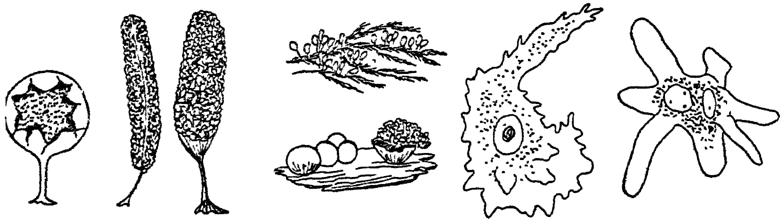

Fig. 102. Slime molds (Myxophyta)

The slime molds (Myxomycetes) are made up of naked masses of protoplasm that have no definite form and contain thousands of nuclei (Figs. 102, 103). They are a group of primitive organisms on the border line between the plant and animal kingdoms. They are like animals in their behavior because they creep slowly over the surface of dead and decaying organic matter on which they feed, engulf bacteria, leaves, and other materials, and digest them within their bodies. The slime

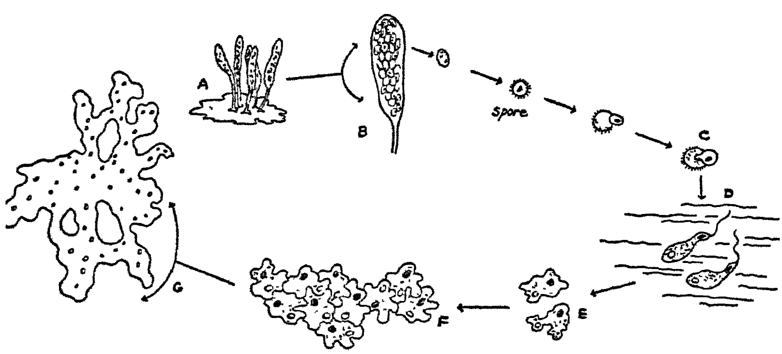

Fig. 103. Life cycle of the Arcyria slime mold: (a) sporongia or fruiting bodies, (b) enlarged fruiting body with spores, (c) germinating spores, (d) swimming or flagellate stage, (e) ameboid stage, (f) fusion of gametes, (g) plasmodium or adult stage

molds are classified as plants, nevertheless, because they reproduce themselves by forming spores, which are sometimes covered with cellulose. Sometimes thousands of these swimming spores join together, germinate, and form a new colony. Under unfavorable conditions the spores surround themselves with a thick protective covering enabling them to remain dormant until better conditions for growth are present again. When there is an abundance of food and moisture the molds can live for many weeks, and some may grow to become several inches in diameter and about half an inch in thickness.

ALGAELIKE FUNGI

The primitive molds, blights, white rusts, and their relatives are grouped together in the algaelike-fungi (Phycomycetes) class. Some of these low forms of vegetation are descendants of very simple fungi, others are degenerated green algae. These elementary plants are either single-celled organisms or made up of strands of thin filaments, without any cross walls, which are filled or lined with continuous strands of protoplasm containing many nuclei.

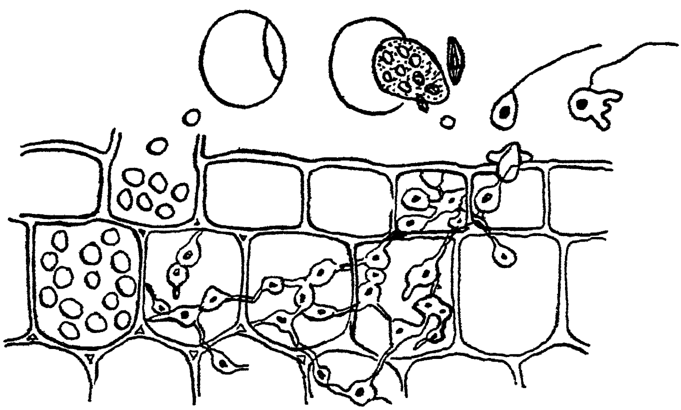

Fig 104. Life cycle of pond scum parasite (Chytrid)

The chytrids are single-celled naked bits of protoplasm that are sometimes slightly branched (Fig. 104). Most of them are parasites living within algae, water fungi, and pollen grains that fall into water. A few, such as the potato scab and club root of cabbage, cause galls, warts, tumors, and other serious deformations in seed plants. Under unfavorable conditions they form thick walls and change into resting spores. The chytrids reproduce themselves by forming swimming spores.

The water molds (Saprolegniales) are probably degenerate descendants of green algae (Fig. 105). The feeding filaments are made up of

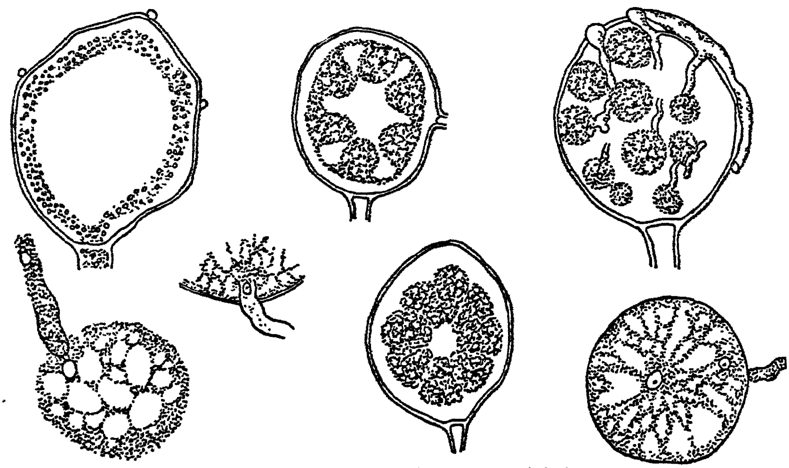

Fig. 105. Water mold (Saprolegniales)

slender tapering threads that penetrate into the host. Most are saprophytes and live on the bodies of dead insects and shell-bearing marine animals, and on other decaying organic matter. A few species are parasites and attack living fish and fish eggs. They cause a great deal of damage when they infest the eggs and young in hatcheries. When they are mature the water molds reproduce themselves by both sexual and asexual means.

The white rusts (Albugo) (Fig. 106), which attack members of the mustard family, the late blights (Phytophthora) of potatoes, the dreaded damping-off disease (Pythium) of seedlings, the downy mildews (Peronospora), and their relatives are sometimes grouped together as members of the Peronosporales class. They are all parasites and cause a tremendous amount of damage to many seed plants. The amount lost in crops and the cost of controlling these fungus diseases run into many hundreds of millions of dollars annually. They are especially harmful to grasses such as corn, sugar cane, and wheat, and frequently attack alfalfa, clover, cucumber, grape, hop, lettuce, onion, sunflower, and tobacco plants.

When a spore of a downy mildew (Pernospora) germinates on the surface of a leaf or stem, the filaments enter the inner tissues, branch out in all directions, and form special feeding tubes that penetrate into the cells, often killing the host (Fig. 100-G). They reproduce themselves by vegetative means, when they form chains of spores called conidia. These are produced in great numbers and are spread by winds over large areas. When a conidium falls on a proper host plant it produces many dry or swimming spores, each of which germinates and

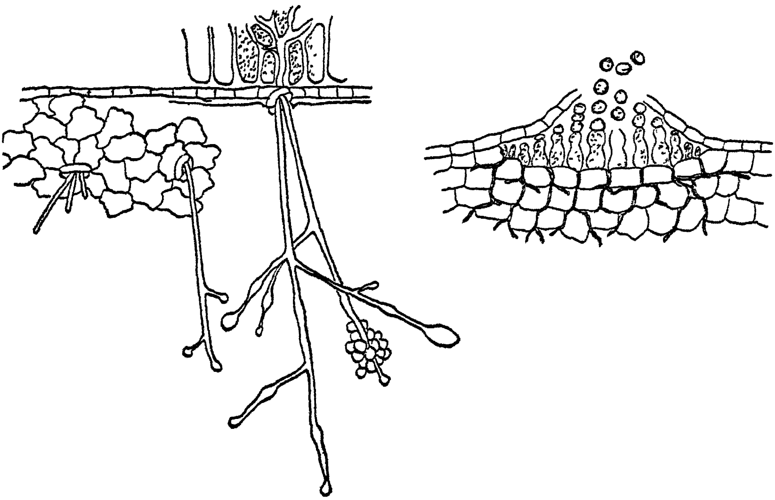

Fig. 106. (Left) Grape mildew (Plasmopara); (Right) white rust (Albugo)

forms new growths that enter into the host. A single conidium falling on a plant may produce so many separate growths, which in turn are able to multiply so rapidly, that, although they are microscopic in size, they can kill a large land plant in a short period of time. Some of these fungi are also able to reproduce themselves by sexual means within the tissues of their hosts. They form swimming zygotes that circulate inside the host and penetrate into the uppermost branches and the deepest roots and tubers.

The late blight (Phytophthora) of potatoes became so destructive in Ireland in 1845 that it caused a great famine and forced thousands of families to leave that country. The terribly destructive nature of these fungi spurred the search for some means by which they could be eradicated. After many years of experimentation it was found that a solution made up of copper sulphate, lime, and water would prevent the germination of the spores and the entry of the filaments into the tissues of higher land plants. This chemical is called Bordeaux solution because it was first used successfully in combatting the downy mildew (Plasmopara) of the famous wine grapes growing near the port of Bordeaux in France.

The true molds (Mucorales) include a few parasites that are responsible for the flower and fruit rots of certain seed plants, and a great number of saprophytes that cause damage to all kinds of foodstuffs (Fig. 107). None of these are found in water; they are exposed freely to the air. Their spores are abundant everywhere, and they settle and germinate on bread, rotting fruits and vegetables, preserves, and other

moist and decaying organic matter, where they form soft cobweblike growths. Although the mycelium is light brown or colorless, these organisms are usually called black molds because their spores are black. The vegetative spores are produced in dark spherelike structures that grow on the tips of tiny, strong, erect, stemlike growths. In one genus, Pilobolus, the entire sphere is thrown up several feet in the air, where it bursts open to spread its spores over a wide area. The spheres seem to be sensitive to light, because they always open at the side receiving the strongest illumination. The spores germinate directly into new plants. The true molds also reproduce themselves by conjugation, when two different filaments approach one another and come in contact end to end. Certain relatives of the true molds are parasites on common house flies and other insects.

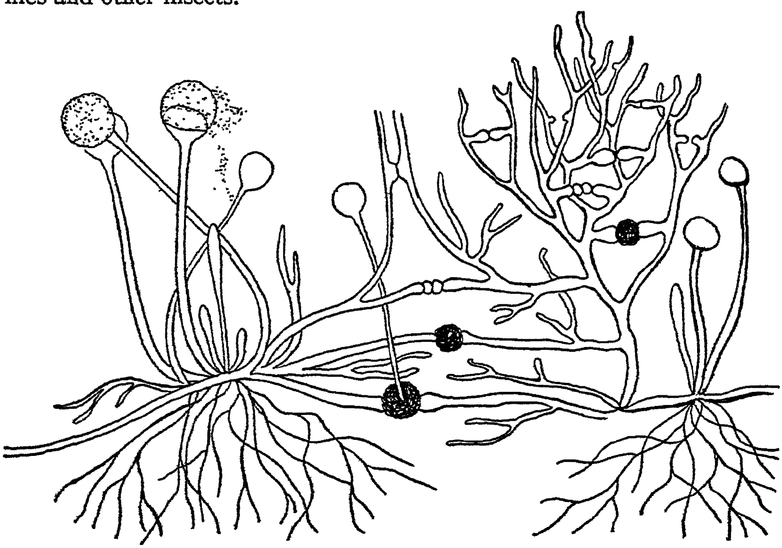

Fig. 107. True mold or black mold (Mucorales)

The common bread molds (Rhizopus) and other true molds are able to propagate themselves by sending forth strong stemlike growths that resemble the runners of strawberry plants. Each of these filaments has a tiny new plant with absorbing tubes at its tip. The tubes penetrate the host, become independent, and later send out new runners, so that in a short period of time the entire surface of the host is covered with a dense net of these growths.

Sac Fungi

The sac fungi (Ascomycetes) are the largest group of known fungi, consisting of over forty thousand species. A great variety of growths

that are widely distributed and of considerable economic importance are included in this class. Some, like the yeasts, penicillia, and truffles, are saprophytes used in brewing beer and in manufacturing different kinds of cheeses and medicines, or are prized food delicacies. Others are parasites and cause many devastating plant diseases. They may be single-celled or made up of many filaments that are divided into cells by cross walls. Each cell usually contains a single nucleus. In some species the cells are organized into definite fleshy bodies, in others the filaments form indefinite cottony growths. Most sac fungi propagate themselves by a complicated reproductive system whereby sexual and asexual methods are alternated. Although the ancestry of many is unknown, most ascomycetes are considered to be degenerative forms of red algae and other chlorophyll-bearing thallophytes.

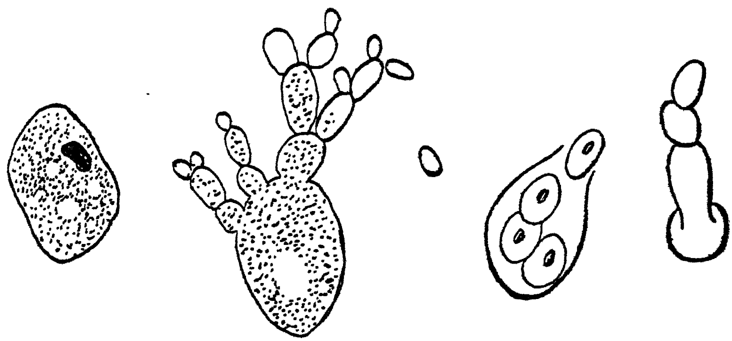

Fig. 108. Yeast (Saccharomycetes)

The yeasts (Saccharomycetes) are minute single-celled or colonial bodies that are not organized into filaments (Fig. 108). They secrete enzymes important in the fermentation of sugars into many kinds of alcohols. They are able to manufacture vitamins, some of which are extracted for human use, and one species is able to form proteins. The yeasts propagate themselves by forming small outgrowths or "buds," and also are able to divide themselves into four ascospores. When the wall of the original cell breaks down, these ascospores are released, and under proper environmental conditions germinate into new yeast cells that start to form new colonies.

Among the simplest filamentous sac fungi are the Exoascales (Fig. 109). The members of the genus Taphrina cause the leaf-curl diseases of peaches and are also responsible for many blister diseases and other disorders on the leaves of forest and orchard trees. These organisms live within the tissues of the host plant and form their fruiting bodies on the surface of the leaves, where the ascospores are exposed to the winds, which distribute them to other hosts.

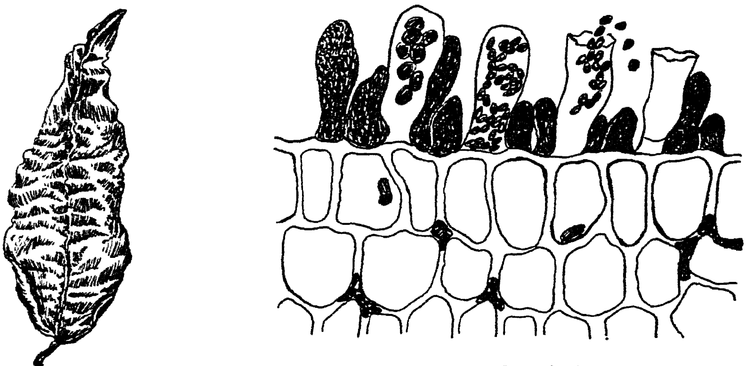

Fig. 109. Peach leaf curl disease (Taphrina)

The cup fungi (Pezizales), morels (Helvellales), truffles (Tuberales), and the powdery mildews (Erysiphales) and their allies are often grouped together in the Discomycetes subclass of sac fungi. Most of the cup fungi are brightly colored harmless saprophytes that live in woods on rotting logs, in damp soils that are rich in humus, and in other organic materials. The Sclerotinia is one of the many parasitic cup fungi that cause brown rots on stone fruits, wilts, molds, and various other rots on many garden vegetables. Truffles (Fig. 110) are usually found near the roots of oak and other forest trees. They grow and produce their fruiting bodies under the surface of the earth at depths of from

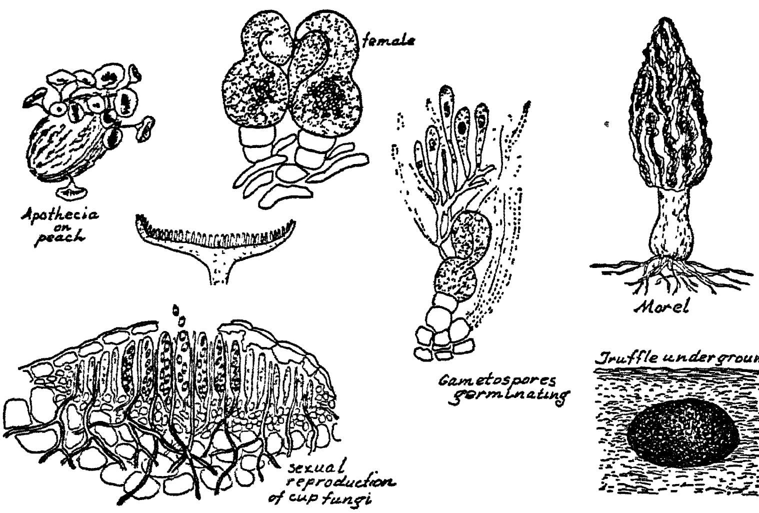

Fig. 110. Cup fungi (Pezizales)

four inches to about a foot. Their spores are spread by worms, rodents, and other creatures that live in the soil. The fruiting bodies vary in diameter from the size of a pea to that of a large orange. They are grayish brown or black in color, firm and fleshy, and have a very pleasant odor and delicious taste. They are usually harvested with the aid of specially trained dogs and hogs whose keen sense of smell enables them to locate these highly prized foods. The edible morels (Morchella) are another group of saprophytic disk fungi that are very fine delicacies. The fruiting body of this much-sought-after fungus grows above ground and is broken up into many irregular-shaped pockets.

The many destructive parasites that form dry powderlike growths on the surface of leaves, stems, flowers, and fruits of many seed plants

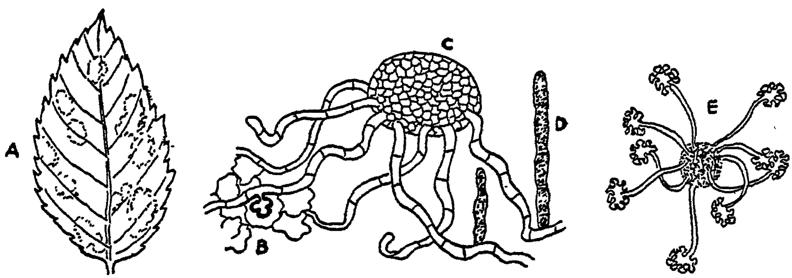

Fig. 111. Powdery mildews (Erysiphales): (a) powdery mildew on elm leaf, (b) absorbing tissues penetrating skin cells, (c) germinating ascospores, (d) erect hyphae, (e) formation of ascospores

are grouped together in the powdery mildew (Erysiphales) order (Fig. 111). The mycelia of these fungi send absorbing tubes into the tissues of the host. The exposed fruiting bodies produce enormous numbers of tiny dry spores on the surface of the host plant, causing the characteristic powdery appearance. The powdery mildews of grasses (Erysiphe) and grapes (Uncinula) are two of the many very destructive organisms of this group.

The black or sphere fungi (Pyrenomycetes) are made up of very dark, hard, compact filaments (Fig. 112). The fruiting bodies of these fungi are usually black and shaped like a flask or bottle. Some are harmless saprophytes, others are very destructive parasites. Ergot (Claviceps) is a terrible disease that attacks the embryos of rye grains and the seeds of other grass plants. This disease is very dangerous to humans and animals because of the toxic substances it produces. In former days thousands of people died when they ate bread that was made from diseased grains. Even today uneducated peasants in many primitive countries are stricken with ergot. A certain species of ergot is cultivated and the enzymes are extracted for use as special medicines. This organism

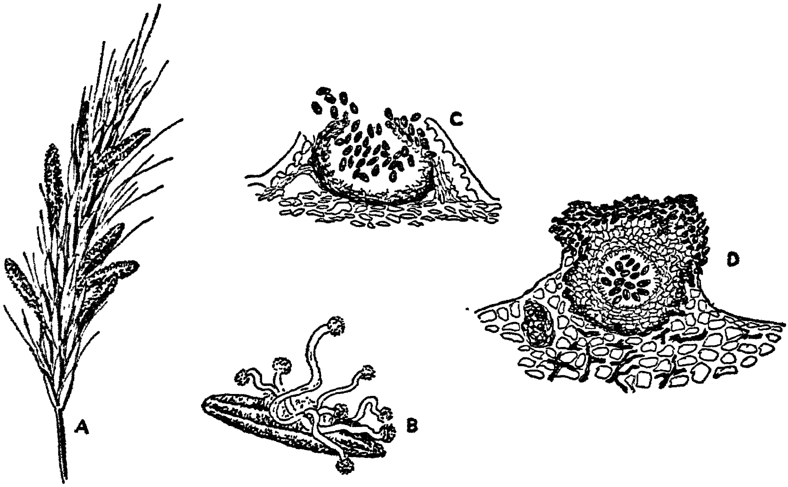

Fig. 112. Black or sphere fungi (Pyrenomycetes): (a) head of rye plant infected by ergot disease, (b) fruiting bodies, (c) enlarged spore sac liberating spores, (d) spores entering a host plant

is controlled by planting disease-free seeds. A few other harmful sphere fungi are the root rot (Rosellinia) of many garden herbs and trees, apple and pear scab (Venturia), chestnut blight (Endothia), which killed off practically all the eating chestnut trees in North America, and black knot of cherries and plums (Plowrightia).

Imperfect Fungi

The green (Aspergillus) and the blue (Penicillium) molds (Fig. 113) have more highly developed filaments than the simple common molds and are believed to be closely related to the powdery mildews. As their

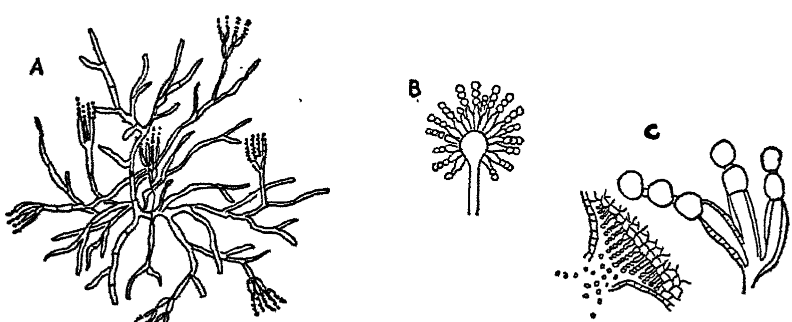

Fig. 113. (a) Blue mold (Penicillium), (b) green mold (Aspergillus), (c) white rust (Albugo)

spores are not enclosed within podlike fruiting bodies like those of other sac fungi, their proper place in the classification of fungus growths is in doubt. In fact, there are still about twenty-four thousand known species of fungi whose life histories are not completely understood. They are temporarily placed within a very mixed group called Fungi Imperfecti. Whenever the reproductive habits of any one of these is learned, it is placed within its proper class, order, family, and genus. Certain anthracnose, blights, cankers, molds, rots, spots, scabs, wilts, and other little-known fungus diseases of many plants, as well as many very harmful and painful skin infections of humans and animals, such as athlete's foot, certain eczemas, and ringworms, are continuously being studied so that the imperfect fungi may be better understood, properly controlled, and classified.

Some green molds (Aspergillus) are saprophytes and form green, red, brown, or yellow growths on leather, decaying fruits and vegetables, cereals, jellies, and other damp substances. Others are parasites and live on figs, dates, onions, and other fruits and vegetables. The blue molds (Penicillium) attack citrus fruits, bread, and other organic materials. Many are of considerable economic value. Some kinds are used in the processing of superior varieties of cheese. One species, *P. notatum*, produces the life-saving penicillin, which kills certain parasitic bacteria and other disease-producing organisms. Many relatives of this mold and other plants are being studied and experiments are being carried out to see if they also contain or excrete substances that have curative and other values.

Club Fungi

The most highly developed fungus growths are grouped in the club-fungi (Basidiomycetes) class. They include the parasitic smuts, rusts, and bracket fungi, and the saprophytic common mushrooms and puffballs. The outstanding characteristic of the organisms in this group is the formation of a special very tiny spore-forming structure that is shaped like a club (Fig. 116). This fruiting organ is made up of either an entire single filament composed of several cells, or more often just the top cell of a filament that produces four spores attached to short slender stalks. Many members of this group undergo a sexual reproductive stage that resembles conjugation sometime during their life cycle.

The smuts (Ustilaginales) are a peculiar group of parasites that attack all grass plants, and are sometimes seen on onions, spinach, and sunflowers (Fig. 114). The disease organism grows within the tissues of the host, and its spore sacs appear on the various aerial parts as tumors, which at first have a grayish appearance. These sacs are often abundant on the flowers and seeds of the attacked plants; they may be

very small on wheat plants, or as large as grapefruits on cornstalks. When the spores are mature, the sac becomes dark in color and opens up to expose billions of dry, black, sooty spores, which make the characteristic large, dark, dirty masses of smutty powder. A certain kind of smut (Tilletia) that attacks wheat plants has a very unpleasant odor and is called stinking smut or the bunt disease of wheat.

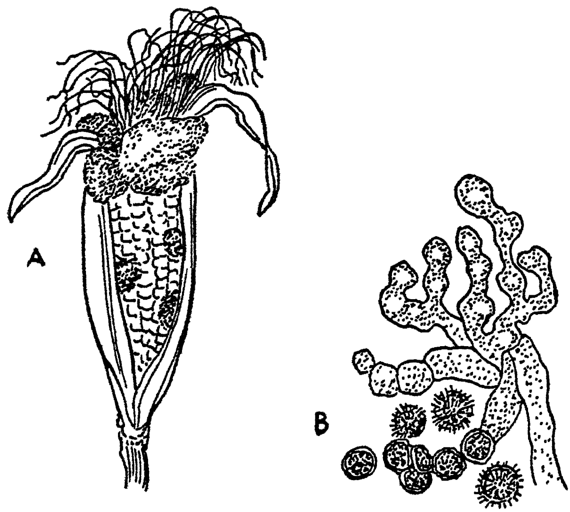

Fig. 114. (a) Corn smut (Ustilago), (b) formation of spores in a kernel of corn

The rusts (Uredinales) include some of the most important plant parasites, and attack practically all seed plants (Fig. 115). They are especially harmful to all cereals, grasses, hay, and other forage crops, vegetables, fruits, ornamental plants, and some forest trees. In years when the attacks of the black stem rust of cereals (Puccinia) are especially epidemic, hundreds of millions of bushels of grain are lost. They are one of the few living organisms that can live only on the living tissues of other plants and cannot be cultivated in culture solutions even when these are made up from the host plants. Although most of the spores are usually black, the common name of this order is due to the conspicuous tiny orange or red spore sacs that are formed by most species during certain stages in their life cycle.

The rusts live in the spaces between the cells of the host. Their mycelium is made up of filaments that contain orange or yellow oil drops. Sometimes certain filaments send forth absorbing tubes that penetrate the cells, extract essential foods, and distort and kill those cells. They

propagate themselves by a very complicated series of sexual and asexual methods whereby five different kinds of growths, fruiting bodies, and spores are formed. Although a few species exhibit all five stages, many use only three or four during their life cycle.

A peculiar characteristic of the rusts is that most kinds alternate between two different kinds of hosts. They form certain types of growths and spores in one kind of plant and very different types in the other host. The apple rust alternates between apples and cedar, the orange rust between asters and goldenrods, the blister rust between pines and currants or gooseberries, and the dreaded black stem rust between cereals and common European barberry plants. One of the best ways to control this disease is to destroy one of the hosts.

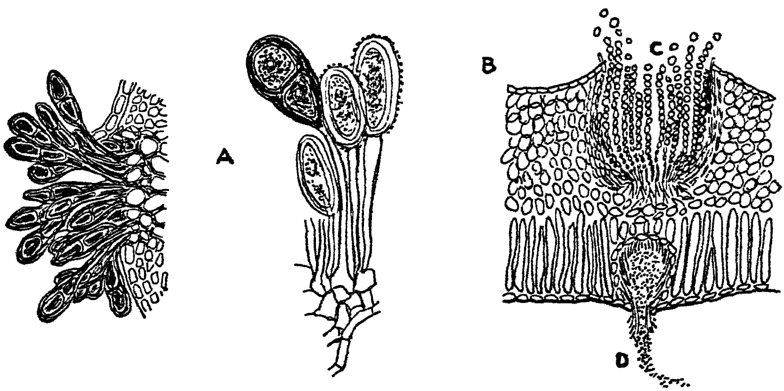

Fig. 115. Rust disease (Uredinales): (a) spore sac of black stem rust, (b) cluster cups in leaf of spring beauty, (c) aesciospores, (d) pychiospores

The majority of the fungus growths that we see in our woods and meadows are the true Basidiomycetes, sometimes known as palisade fungi. Extensive filaments of a few types penetrate the roots, stems, and branches of green plants. Many live in rich organic soils, moldy leaves, decaying logs, rotting stumps, poles, timber, wooden furniture, and other organic materials. When they have absorbed and stored a certain amount of food they form small buttonlike growths. Under favorable conditions these grow very rapidly, tear their covering tissue apart, are exposed to the air, and develop the characteristic fruiting bodies that we see. Such great quantities of spores are produced that a common medium-sized mushroom may have ten billion or more spores and liberate them at an average rate of a million a minute.

The ancestors of the basidium fungi are unknown, and none have evolved into higher forms of plant life. There are over twenty thousand known species, and their filaments, spores, fruiting bodies, and cover-

ings are of many different colors, shapes, sizes, and structures. The types of spore-manufacturing structures they have, and the colors of their spores, are the main characteristics used in the classification of these peculiar growths. Although the form of the fruiting body may change with different kinds of environmental conditions, and the color of the fruiting body may be influenced by differences in alkalinity and acidity of the medium on which they live, the colors of the spores do not seem to be affected. The spores may be black, blue, brick red, brown, pink, purple, red, rose, white, or yellow.

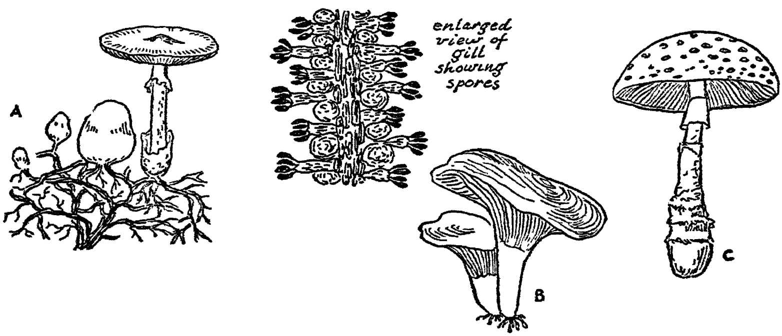

Fig. 116. Gill fungi (Agaricales): (a) imperial agaric, (b) Cinnamon Cortinarius, (c) fly mushroom (Amanita)

The gill fungi (Agaricales) form a very large group that includes the common eating mushrooms, the deadly poisonous toadstools, and many other parasitic and saprophytic growths (Fig. 116). Their club-shaped reproducing organs are arranged on flat plates or gills situated on the underside of the flat, saucer-shaped, or rounded umbrellalike top of the fruiting body. Practically every genus in this group has both edible and poisonous species. Very often the several species within a genus may resemble one another at some stage during the growing period. Therefore, many characteristics must be known and carefully observed when choosing mushrooms in the field. Some species are edible at one stage of their growth and poisonous at another.

Several species of the Agaricus genus are cultivated in special cellars and constitute an important commercial product. One of the best edible mushrooms (*Marasmius oreades*), which is found on exposed grassy places, forms "fairy rings." Some fairy rings are many feet in diameter and are believed to be six hundred or more years old. The honey or oak mushroom (*Armillaria mellea*) is a honey-colored delicious fungus growth that may grow as a saprophyte on the ground, and is also a very destructive parasite causing the death and rot of many

forest and orchard trees. The mycelium filaments of this and several other fungus growths contain a curious chemical substance that glows in the dark. Many milky mushrooms (Lactarius) are good to eat and have white, yellow, or orange fluids, and their tops are usually shaped like saucers. The gills of the edible inky cap (Coprinus) mushrooms dissolve when the spores are ripe and form an inky fluid that drips its black spores to the ground. This fluid makes an excellent indelible ink which, though it looks like other types of ink, reveals its spores under the microscope. This characteristic is often useful in dealing with the authenticity of documents. The most dangerous man-killer of all fungi is the fly mushroom (*Amanita muscaria*); a very close relative of this species, the imperial agaric (*Amanita caesarea*), is one of the most tasty mushrooms and was served at royal feasts in ancient Greece and Rome.

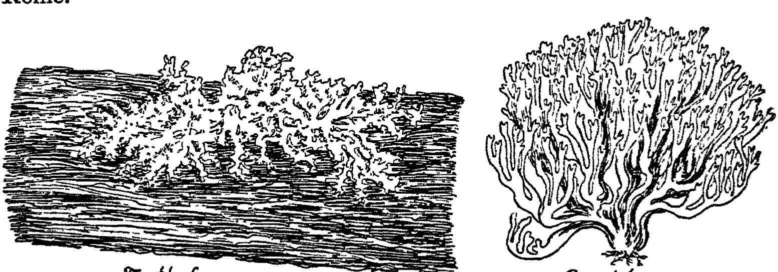

Fig. 117. Tooth and Coral fungi

The upper surface of the cap of tooth fungi (Hydnaceae) is irregular in shape, and the underside is covered with many pricklelike outgrowths (Fig. 117). The coral fungi (Clavariales) are branched mushrooms, most of which are edible. They are of many fantastic shapes and beautiful colors. Some resemble the dancing flames of fires, others are like delicate laces.

The tube or pore fungi (Polyporales) produce their spores on long narrow tubes that have small openings permitting the ripened spores to fall down to earth or drop into the crevices of the uneven bark of trees (Fig. 118). They grow on many different kinds of organic substances, and many are very destructive. The dry rots (Meruliaceae) are made up of thin strands of mycelium and decay all kinds of wooden structures and furniture. One of the most delicious mushrooms is the "Cape" of commerce (*Boletus edulis*), which has a brown leathery covering and many round pores on the undersurface of its cap. The hoof (Fomes), bracket (Polyporous), and shelf (Lenzites) fungi grow on decaying logs and living trees of all kinds (Fig. 118). Many seriously harm and kill

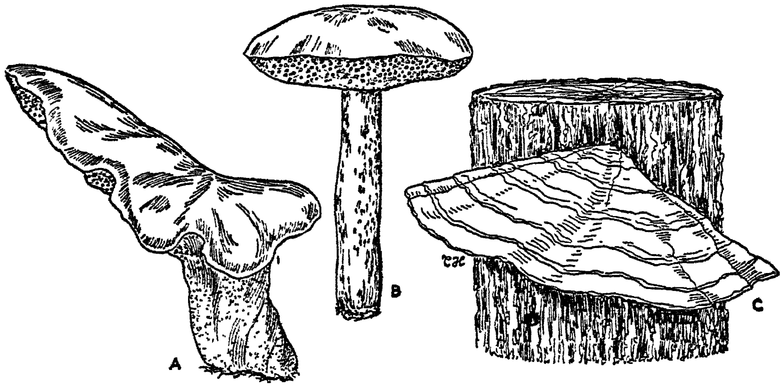

Fig. 118. Tube or pore fungi (Polyporales): (a) beef tongue mushroom, (b) cape mushroom, (c) bracket fungus

their hosts and are among the most destructive of all fungi that attack trees. It is very difficult to eradicate them because their filaments extend deeply into the host. They have tough, corklike woody or leathery coverings of all sizes, shapes, and colors, which protect the soft and fleshy fruiting bodies. They form new layers of porous outer growth yearly, and their age may be learned from counting the annual rings of the exposed fruiting bodies.

The puffballs (Lycoperdales) (Fig. 119) are members of the Gasteromycetes fungi, in which are grouped the most highly developed fungus growths. Their fruiting bodies are almost spherical and have a thick, light-colored, leathery covering that becomes cracked and ruptured at the top when the spores are ripe. Many are small, but the giant puffball (*Calvatia gigantea*) may attain several feet in height and weigh as much as twenty pounds. Many puffballs are edible only when they are mature and their inner flesh is firm and white; when they are very

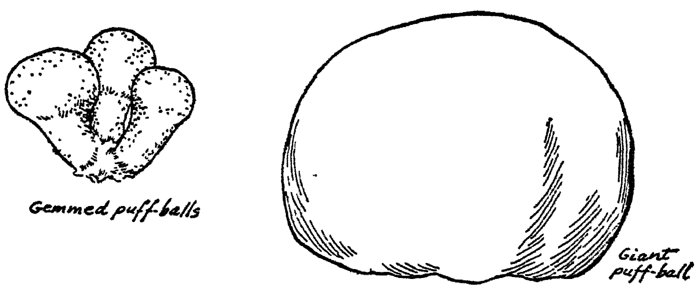

Fig. 119. Puffballs (Calvatia)

young and when they start to form spore cases and change in color they are unfit to eat. They are called puffballs because a medium-sized fruiting body produces about 7,500 billion spores that escape as clouds of fine powdery dust. If each of these grew into a new plant, a mass of fungus eight hundred times the size of the earth would result. The beautiful little earthstar (Geaster) is a close relative of the puffballs. Its spore sac is covered with an outer coat that ruptures when the spores mature into several regularly spaced, star-shaped points around the central round inner spore sac.

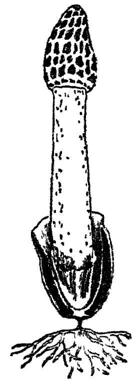

Fig. 120. Stinkhorn (Ithyphallus)

The highest development in the fruiting bodies of fungi occurs in the Phallales, of which the stinkhorn (Ithyphallus) is a well-known example (Fig. 120). The yellow, perforated, fruiting body is supported on a hollow brown stalk. The stalk and fruiting body are covered with a brownish-green, slimy, foul-smelling substance that emits a terrible stench, attracting carrion flies which come and carry away the spores.

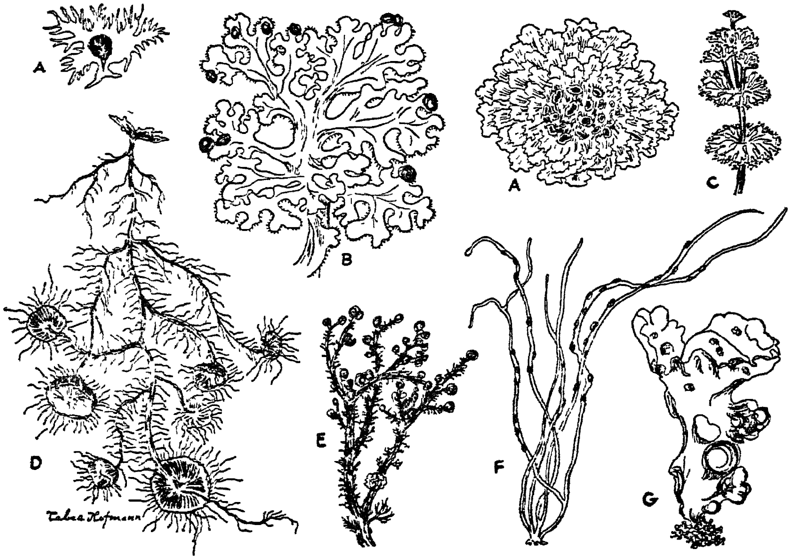

Fig. 121. Lichens: (a) Parmelia, (b) Iceland moss, (c) reindeer moss, (d) old-man's-beard, (e) Stereocolon, (f) Litmus or Cudbear, (g) Collema

23. LICHENS

AMONG the most extraordinary types of organisms of the plant kingdom are the lichens, which are grouped within the third and last subdivision of Thallophyta. These are not single plants, but close structural associations between certain blue-green or simple green algae and various kinds of sac and club fungi. They originate when the spores of suitable kinds of fungi fall on or near congenial algal growths (Fig. 122-E). As the green plant grows in size, the fungus extends its filaments around the food-manufacturing plant. The resulting composite organism assumes various shapes, sizes, colors, and types of growth.

Some fungi partners are saprophytic in character and live on the released by-products of the algae; others form absorbing tubes that penetrate the green plants and extract the manufactured foods. In a few cases the alga is eventually killed by the fungus, which continues life as a saprophyte until all the food is used up. The fungus is often beneficial to its partner, furnishing it with water and mineral salts from the air, rocks, soils, and various organic materials. The fungus also forms a thick protective covering that supports and anchors the association in

places where the algal plant would be unable to live alone. Such beneficial give and take between two different kinds of living organisms is called symbiosis, and occurs frequently in nature between different kinds of plants, some plants and animals, and various animals.

The food-manufacturing algae may be green, yellow, brown, blue, red, or purple in color. They are usually found as small round bodies that are imprisoned by many tough filamentous strands of the fungus partner (Fig. 122-F). These bodies are arranged near the upper sur-

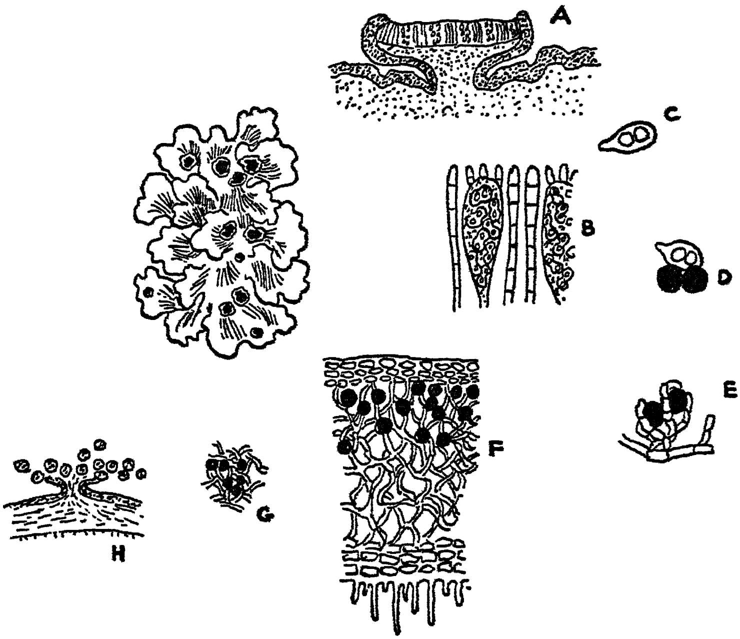

Fig. 122. Reproduction of lichens: (a) fruiting body, (b) spore sacs, (c) fungus spore, (d) fungus spore alighting on algae, (e) fungus mycelium enveloping algae, (f) algae partners imprisoned within fungus mycelium in an adult lichen plant, (g) enlarged sorus, (h) vegetable spores or sori being released

face of flat reclining lichens. In upright and hanging forms they are more or less evenly distributed so that light can penetrate and reach them from all sides. During periods of drought most lichens are very dry and brittle, and the older parts may be torn into shreds by winds. Under favorable conditions and on proper surfaces these fragments grow into new separate associations. Lichen associations are also able to propagate themselves by other vegetative means. The fungus partner is able to produce its particular fruiting bodies and spores independently of the alga. But the green partner, which is tightly wedged within the

mycelium, is unable to reproduce itself independently. All the new growth that it forms is always imprisoned within the fungus.

The type of association varies, but each pair is sufficiently distinct to be recognized as a definite lichen species. Over ten thousand species of lichen associations have been recognized and named. They are widely distributed over the earth's surface, and thrive on bare rocks, soil, and other exposed places where no other vegetation could exist. They prefer cool, damp, shady places and are especially abundant in the cold, foggy, arctic lands.

In the simplest kinds, such as the Collema (Fig. 121-G), which grows on soils and barks of trees, the fungus filaments penetrate the gummy walls of the algae. These types of organisms are spongy and very gelatinous when moist. They are very dry and brittle during dry seasons.

Many lichens are the land pioneers of the plant kingdom, being the first living organisms to colonize barren rocky areas. These types of growths are called crustaceous because they resemble hard, flat, thin, brittle crusts of matter, red, gray, blue, or black in color, that cling very closely to the rocks. They have tiny hairlike absorbing tubes that excrete weak acids that dissolve the hard rocky material. The manna of the Bible (Lecanora) is one of the most famous crust lichens. This plant lives on exposed rocks and hard sandy sections of Syria, Palestine, Egypt, and surrounding countries. During periods of drought its delicate brittle structure is broken up into many small pieces that are blown about by winds and settle in low protected places. These accumulations are gathered by the natives and ground into a flour, which is made into a nutritive, sweet-tasting bread.

The rock tripe (Umbilicaria) and parmelias have the foliose type of lichen structures and resemble leaves (Fig. 121-A). These flat reclining growths are arranged in rosettes and have irregularly raised edges. They are able to take root and grow on rocks after the crust lichens have accumulated a certain amount of organic material and changed the hard surface into primitive soil. They are attached to various kinds of surfaces by short rootlike absorbing filaments.

Most of the economically valuable lichens are branched upright or hanging growths that resemble mosses, and are called fruticose lichens. The Iceland moss (*Cetraria islandica*) grows erect and has a light bluish-green or brown color (Fig. 121-B). It is used as a source of gelatin and serves as a food to Icelanders and other arctic people. It is the only lichen that is listed as an official medicine in many countries. The reindeer moss (Cladonia) (Fig. 121-C) grows in many places all over the world, and is especially abundant in the almost continuously frozen tundra lands of the far north. It is one of the main foods of reindeer. Certain species of Ramalina and Evernia lichens are sometimes called

oak mosses. They have very pleasant penetrating odors and are widely used in the perfume industry. The blue and violet dyes commonly known as archil, cudbear, and orseilline are extracted from *Roccella tinctoria* (Fig. 121-F), which is an upright plant that has many very stiff branchlike filaments. Several species of the Roccella lichens are used in the manufacture of litmus, which is widely employed in testing the acidity or alkalinity of substances. Litmus is a purple substance that becomes red when placed in an acid, and changes to blue in an alkali solution. Old-man's-beard (Usnea) (Fig. 121-D) is a very thick growing hanging lichen that has long grayish strands that hang down from trees. It looks very much like the Florida or Spanish mosses, which aren't mosses at all, but members of the pineapple family.

Fig. 123. Plant amphibians (Bryophytes)

24. FROM WATER TO LAND

THE colonization of land by plants was one of the most significant achievements of living organisms. The successful establishment of vegetation on mud, damp soil, and rocks pioneered the exploitation of a tremendous variety of new habitats exceedingly rich with great treasures of nutrients and many new environments, which led to the evolution and wide distribution of the many and different marvelous kinds of land plants, animals, and humans present on the earth today. The transition from a water to a land environment was a very advantageous step for plants, because their chlorophyll bodies can work with greater efficiency, accumulate more energy, and produce more food when manufacturing cells are exposed to the atmosphere than when in water, which contains less oxygen and carbon dioxide, and which reflects and absorbs most of the vital energy-giving light rays.

In exposing themselves to the relatively dry air, plants had to undergo many changes in their internal structures, outer forms, and reproductive habits. Millions of spores and fragments representing many different kinds of algae must have fallen on land and died before the first few were able to establish themselves. Those that succeeded transmitted the beneficial mutations that occurred from time to time, and little by little the mutations accumulated during long geological periods that extended many millions of years, until the present-day land plants came into being. There are hardly any traces of those ancient transition ancestors left as fossils, and none is a part of present-day vegetation.

Among the most primitive green land plants growing today are the mosses, liverworts, and hornworts, which are grouped together within

the second great division of the plant kingdom known as Bryophyta (Fig. 78). These are living representatives of intermediate vegetation between aquatic algae and the vascular plants that have true roots, woody stems, and leaves. They are not the ancestors of the ferns and other forms of land vegetation, but the living remains of one of the many side lines that were developed during the evolution of plant life from which no higher types evolved.

The bryophytes live in many different habitats all over the world. Most are very small, and many would be inconspicuous if they grew singly. As they have a habit of growing in close associations, they are seen as short, usually light, green mats of vegetation. Some reach heights of several inches, and a few grow into long, dense, hairlike festoons. Many grow on damp rocks, in moist soils, in sheltered nooks, and on logs. Certain kinds are able to live as attachments on the trunks and branches of trees. A few can exist in dry desert areas where they experience long periods of drought, and appear as dry, dead, gray or brown strands. They become green and grow vigorously during the short rainy seasons. Other forms live on the almost continuously frozen tundra formations of polar lands. Some grow partially submerged in water and form bogs and marshes. A few are degenerate plants that probably resemble some of their ancient aquatic ancestors.

Although many different kinds of plants having various types of structures and growing habits are included within the Bryophyta division, they all have several features in common. Instead of having true roots, they possess tiny hairlike holdfasts. These primitive anchoring structures are able to absorb some water and mineral salts when they are young and alive. They usually dry out and die soon after they are formed, and the absorbing activity is undertaken by those body cells that come in contact with air and the surface on which the plant is attached. When the bryophytes are mature their entire surface is covered with a skinlike layer of protective cells that is punctured with many small pores that permit the exchange of gases with the air, and release water. Although the cells that make up the primitive stemlike and leaflike attachments of many bryophytes are specialized, they are not permanently changed, and retain their dividing power. When older parts of these plants are torn into fragments and scattered by winds, they can grow into independent individuals when they settle in proper environments.

The green independent land plant that we see is the gametophyte generation that reaches its highest development in this division of the plant kingdom.

Male and female organs may be produced on the same or on separate individuals (Fig. 124). The male organ, called an antheridium, produces tiny swimming male gametes, which swim through water, contact

and fuse with the female gamete to form the zygote. The sporophyte that develops from the growth of the zygote is a tiny structure that derives part or all of its food from its female parent. It is permanently attached to its female parent and never touches the ground. In time the sporophyte develops an urn-shaped capsulelike structure that produces numerous gametophyte cells in the form of spores. Some moss relatives bear spores that contain both sexes. Spores are released when ripe, and if they fall on proper damp places eventually develop, by several stages, into the prominent green independent gametophyte plants.

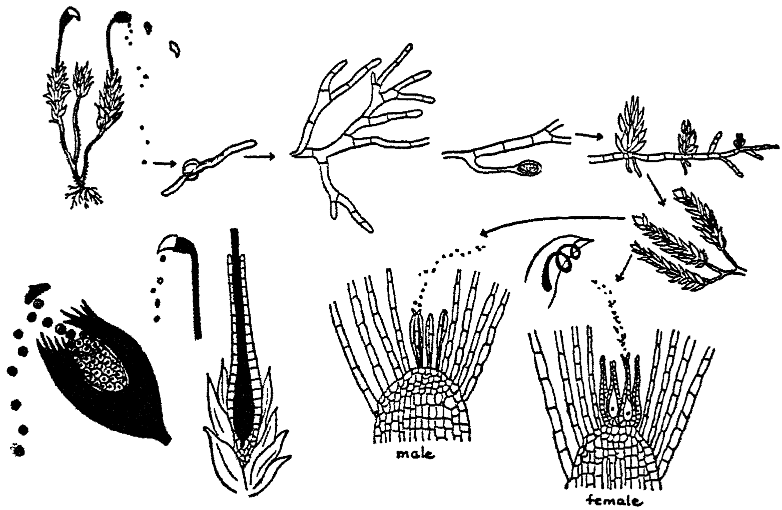

Fig. 124. Life cycle of moss

Many bryophytes are able to reproduce themselves directly without forming sexual organs and without passing through a sporophyte generation.

Sometimes fragments of the sporophyte generation are separated from the parent plant body and grow into independent green plants that have two sets of chromosomes. These are called aposporous plants and produce gametes and gemmae that have two sets of chromosomes. When the gametes of these plants fuse with those of the gametophyte plants, the resulting offspring have three sets of chromosomes; when they fuse with each other they produce growths that have four sets of chromosomes.

Mosses

Although many plants belonging to other groups are called mosses, the only true ones are members of the Musci class of Bryophyta. They

are world-wide in distribution, being able to grow in every kind of habitat that can support vegetation. The majority prefer moist places, but some are able to grow in dry desert areas.

Among the many thousands of species of mosses there is a great diversity in size, form, and structure of the prominent gametophyte generation. In size they range from plants that are hardly visible without the aid of a magnifying glass to certain water mosses that may reach a foot or more in height.

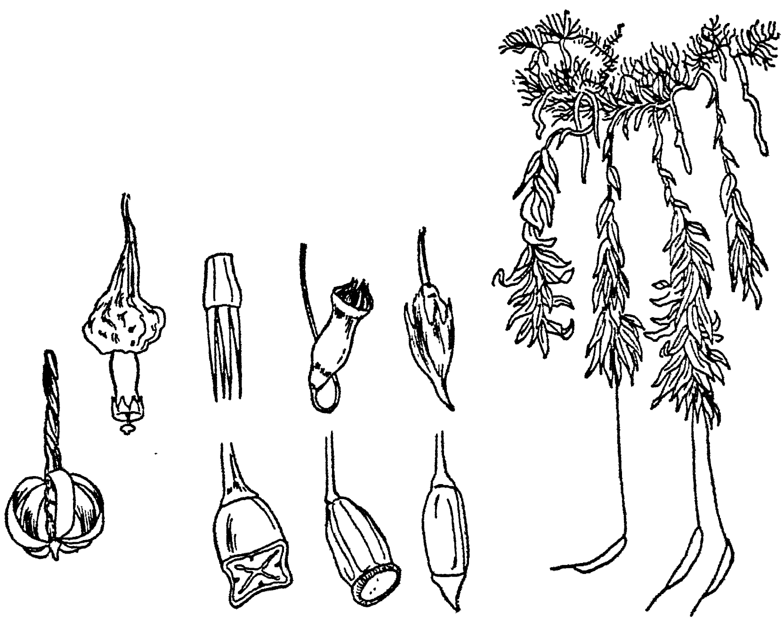

Fig. 125. Moss plant and spore-forming capsules

The true mosses, or Bryales, give the entire division its name (Fig. 125). They are found everywhere that plant life can be supported with the exception of salty waters. A few are aquatic, many live in deserts, but the majority grow in shady woods on damp rocks, decaying logs, barks of trees, and in moist soils. In most species the original filament disappears after the erect stems have formed their own rootlike absorbing tubes, called rhizoids, and have established themselves. In low forms there is only a slight differentiation of cells; in the higher types specialized cells are differentiated into primitive tissues.

The Andreaeales are a group of very small dark-colored mosses that resemble the Bryales but grow exclusively on rocks. The peat, bog, or Sphagnum mosses are members of the third and last order of Musci

(Fig. 126). They grow all over the world, but only in moist places. In the cold polar regions they grow in combination with the lichens and other bryophytes and form the conspicuous part of the vegetation of those tundra lands. In temperate climes they grow in damp soils, wet meadows, and lakes and ponds.

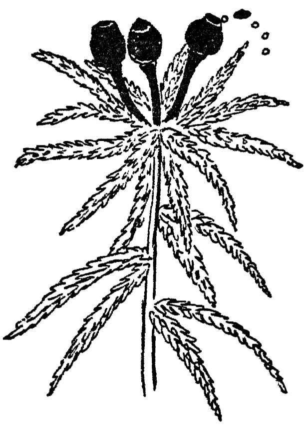

Fig. 126. Sphagnum moss; sporophyte growth in black

The Sphagnum mosses play an important role in converting lakes and ponds into swamps and bogs that are later changed into dry land. When small bodies of water support a rich vegetation they are usually acid. This is an unfavorable condition for many saprophytes. Instead of rotting, the dead remains of these mosses are partly decomposed into peat. As new accumulations of peat are added, a suitable surface for the growth of higher types of vegetation is formed. The peat formations, in time, are changed to coal.

The leaves of these plants have no midribs like those of the other mosses. They have many large porous cells that are able to absorb as much as two hundred times their own weight in water. The sphagnums make excellent surgical dressings, and are also used as packing material because they can retain such great quantities of water. The female organ grows from the tip of the gametophyte plant, while the male structures are formed along special side branches. The entire sporophyte consists only of a dark spherical capsule that is borne on the end of a long, stalklike extension of the female organ.

Liverworts

The liverworts and their relatives are grouped within the Hepaticae class of Bryophyta. Hepatica is from a Greek word meaning liver, and this name was given to the entire group because the true liverworts resemble the lobed liver of human beings, and these plants were supposed to have special curative values against liver disorders. There are several orders of Hepaticae representing distinct and more or less parallel lines of development, probably from green algae. Among the most widely distributed kinds of liverworts, there are the Marchantiales, which have a thickened, sometimes fleshy, flat type of plant body; and the leafy forms, represented by the Jungermanniales, which are sometimes called scale mosses. The spores of all these plants ger-

minate into tiny flat growths that are tightly attached to moist surfaces by rhizoids.

The leafy liverworts (Jungermanniales) (Fig. 127) resemble the true mosses to a limited degree. They can be distinguished by their curiously shaped leaves that often serve for the capture and storage of water. The leaves are arranged in regular rows along the thin short stems, as opposed to the spiral arrangement of the leaves in true mosses. The scale mosses are seldom erect, usually growing along the ground, where their many delicate stems and leaves resemble fine lacework. They are found on damp soils and rocks, on decaying logs, and on tree

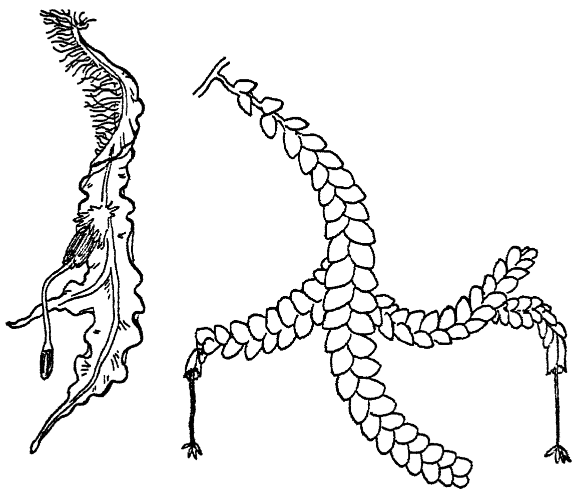

Fig. 127. Scale moss (Jungermanniales)

trunks in damp forests. The female structures are situated at the tips of the plants, and the male organs are placed on side stems. When the spores are ripe and ready for dispersal the capsule of the sporophyte splits into four petal-like sections.

The liver-shaped fleshy Marchantiales are true liverworts (Fig. 128). The plant body is made up of several thick leaflike structures superimposed on one another. The plant is a reclining, sometimes branching, growth with rhizoids growing from the undersurface. It is rarely more than three or four inches in length, and a half inch in width. Many air chambers containing elongated manufacturing cells are present along the upper portions just below the protecting covering layer of cells. The air chambers are connected with the atmosphere through a system of four chimneylike cells. The gametophyte generation of

the Marchantiales is represented by separate male and female plants. The fruiting bodies are placed on erect stalks that arise from the upper surfaces of the mature plants. The male structure is a flattened saucer-like disk in which the male organs are imbedded. These open into the upper surface of the disk when the swimming male gametes are ripe and the surface is covered with water. The female disk has several, usu-

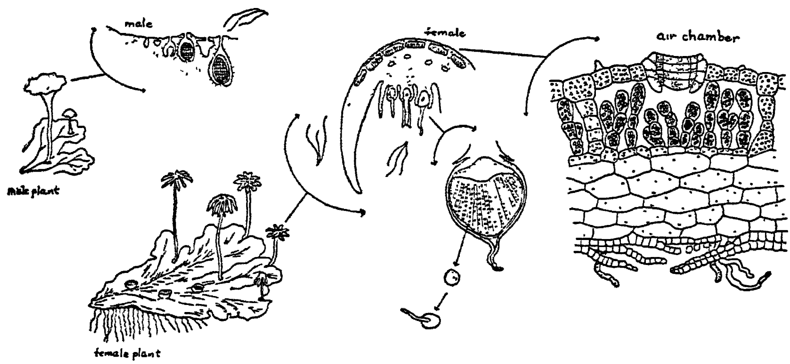

Fig. 128. Reproduction of Marchantia liverwort

ally nine, umbrellalike ribs. The female structures are borne on the underside of these ribs with their necks pointing downward. The very tiny mature sporophyte also hangs downward and simply drops its spores when they are ripe. Practically all liverworts produce many conspicuous cuplike growths on their exposed surfaces, in which asexual spores are produced.

Hornworts

The highest forms of Bryophyta are the hornworts (Antaocerotales) (Fig. 129). The gametophyte is a small, fleshy, lobed, thickened, platelike, light green plant. The lower surface has many tiny slitlike openings leading into gummy chambers that are sometimes invaded by the blue-green algae, Nostoc. Both male and female fruiting bodies are found on the same individual. The male organs are produced in special chambers that are imbedded within the tissues of the plant. The male gametes swim to the female organs where the plant is covered with moisture. They have a very short distance to travel, and their entrance into the female organs is greatly facilitated because the uppermost neck cells of the female structures are flush with the surface of the plant. After the female gametes have been fertilized the female structures are covered by surface cells.

Although the gametophyte generation is represented by a comparatively simple plant body, the sporophyte structure is very complicated

and almost self-sufficient. Its absorbing structure or "foot" is made up of several, sometimes branched, rhizoidlike absorbing tubes. The upper portion grows by forcing its way through the covering layer of cells and reaches a length of from one to several inches. It is supported by a sheath of cells that are formed by the parent. This long tubelike exposed upper portion consists of a wall several layers of cells in thickness, which encloses the spore-forming tissues. The outer cells of the wall have chlorophyll bodies that manufacture food for the use of the sporophyte, and the skin is punctured by many air pores. These openings are very similar to the stomata of the highest vascular plants, in that the openings are regulated by two guard cells. Inside the tube there is

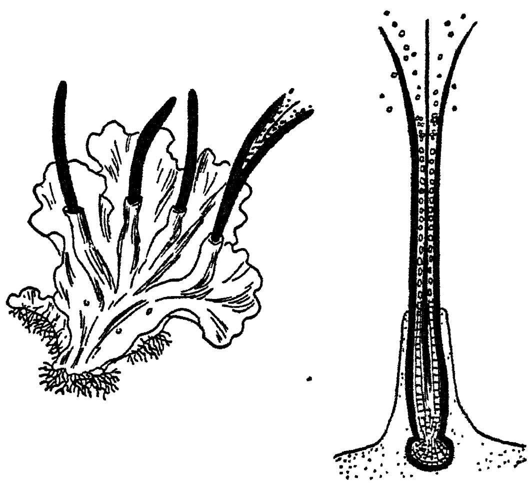

Fig. 129. Hornwort (Anthoceros)

a long thin column around which the spores are developed. Many dividing cells are situated at the bottom of the tube, and they constantly add new spore cells to the column and new body cells to the elongated tubelike capsule as long as the sporophyte is alive. When the spores are ripe, the capsule starts opening at the top by splitting in two. As old spores are released and new ones are being added from the base, the capsule continues to split downward, exposing the column and spores. The long open capsule resembles the horns of some animals.

In the hornworts we have an example of what might have been the highest development achieved by a dependent, permanently attached sporophyte. In all the following forms of vegetation the sporophyte generation develops into an independent green land plant, while the gametophyte is gradually reduced to an almost invisible growth.

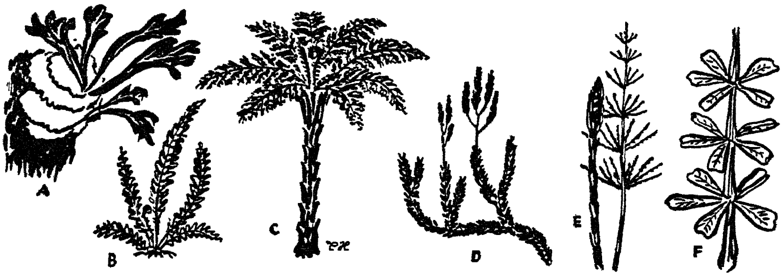

Fig. 130. Pteridophytes: (a) staghorn fern, (b) polypody fern, (c) tree fern, (d) club moss, (e) horsetail, (f) fossil fragment of ancient sphenophyllum plant

25. LAND SPORE PLANTS

IT is of great interest to note that all primitive plants up to and including the bryophytes pass the prominent and independent stage of their life as gametophytes, while all green land plants that have true leaves, roots, and specialized conductive tissues are sporophytes, and possess two sets of chromosomes. It is probable that both transition from water to land life and the transformations that were involved in changing from an independent gametophyte to an independent sporophyte played interlocking roles during the course of evolution. It may be that successful permanent establishment on land depended upon the extra stimulating, co-ordinating, and directing factors that two sets of chromosomes are able to exert, while just one set was not enough. In primitive gametophyte plants practically all cells remain alive, very few are radically and permanently changed, and simple substances only are produced. In sporophytes the cytoplasm is able to manufacture many different kinds of complicated substances; the walls of some cells may become so thickened and modified that they reduce the amount of living substance, and in some cases use up all the protoplasm and change into dead protecting, supporting, and conductive tissues.

PSILOPHYTES

A certain primitive group of uncovered fossil remains and two living genera of plants show us what the most simple forms of independent sporophytes may have looked like (Fig. 131). All these plants are united into a group called Psilophytales, which is from two Greek words meaning, roughly, small thin plants (Fig. 78). They seem to have been the most abundant land plants about 350 million years ago, and fossil remains of these have been found in many parts of the world.

One of the best-known fossil psilophytales is the Rhynia plant. This plant had an underground stem from which several thin, simply fork-

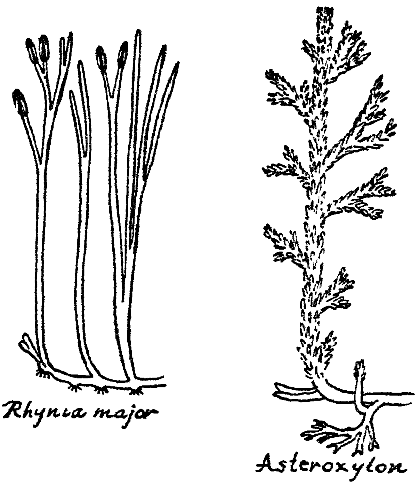

Fig. 131. Reconstruction of fossil psilophytes

ing branched stems formed a rushlike growth about two feet high. The stem had a simple vascular cylinder made up of typical wood cells, which were surrounded by bast and resembled the stems of the vascular plants of today. There were no true roots, but multicellular branching absorbing tissues that we call rhizoids. The plant had no true leaves, and the manufacturing cells and stomata were situated directly on the stem. The spore-forming capsules were borne on the ends of branches, and the spores seem to have been all alike. Another well-known primitive fossil plant is the Asteroxylon. The lowest parts of the stems of these plants were covered with leaflike scales, and the upper parts were naked.

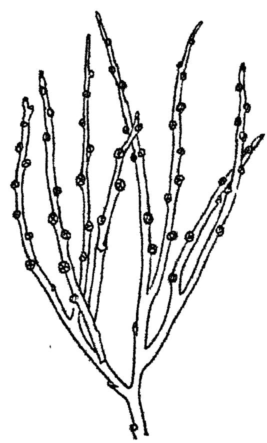

Fig. 132. A present-day living psilotum plant

The Psilotum plant (Fig. 132) is a living fossil that is believed to have remained unchanged for many hundreds of millions of years. It is found growing only in certain restricted areas in Australia. These plants resemble their fossil ancestors in many ways. Their green branches produce many leaflike scales that are provided with stomata. Their spore-

forming structures are three-lobed and are placed at the axils of the leaves. The spores are all alike and germinate into very tiny juvenile growths that bear the reproductive organs. The zygote develops its own root, stem, and leaves, and eventually roots itself and becomes independent, while the gametophyte shrivels up and dies away.

It has been estimated that there are over 7,400 billion (7,400,000,000,000) tons of coal deposited at different levels within the earth's crust up to depths of about a mile. At the present rate of consumption this vast amount of coal will probably last man about three thousand years. Almost half of all this rich fuel is in the United States; 19 per cent is in the north polar regions, Canada, and Latin America; 17 per cent is in Asia; 10 per cent is in Europe; 5 per cent is in the south polar regions, Australia, Japan, and other Pacific islands; and the remaining 1 per cent is in the African continent.

It appears that a seam of coal one foot in thickness is the result of the change and compression of a layer of vegetation that was ten feet thick. The immense amount of coal in the earth's crust therefore represents the accumulation of ten times its bulk of vegetation. When we realize that only a small percentage of the plants living in ancient days were changed into coal, we may have some glimmering of the tremendous amount of plant life that thrived at various periods during the earth's history.

The earliest coal deposits are found in between rocks that were laid down during the Silurian period, about 460 million years ago, when the psilophytes started to dominate the land (Fig. 78).

The most primitive group of vascular plants that evolved from the psilophytes consisted of the direct ancestors of our present-day club mosses, or lycopods. They made their appearance during the beginning of the Devonian period, about 450 million years ago, and did not give rise to higher forms of plant life. These trees and their relatives were a very conspicuous part of the land vegetation during the Devonian and Carboniferous periods, and became one of the most important sources of coal.

In those days of long ago, one genus of lycopods (Figs. 77-A, 133), the Lepidodendron, had wide-spreading large underground stems, a single erect scarred trunk over a hundred feet in height, and a widely spread branched top. The upper branches were completely covered with leaves that were from several inches to over a foot in length. The trunk and the lower parts of the largest branches were marked with scars left by former leaves that had been shed, and the large conelike fruiting organs were borne at the tips of the outermost twigs. Another genus of this group, the Sigillaria (Fig. 133), slightly resembled certain present-day palm trees. It had a tall unbranched trunk. Its leaves, which were

sometimes over three feet in length, grew from the single terminal growing point. The cones were distributed around the trunk just below the leaves.

For some unknown reason the lycopods were unable to survive as large trees. Representatives of the smaller species only are found as fossils after the Permian period of about 300 million years ago.

The present-day living club mosses have true roots, stems, and leaves. Most are small, delicate, low-growing, mosslike plants that creep along

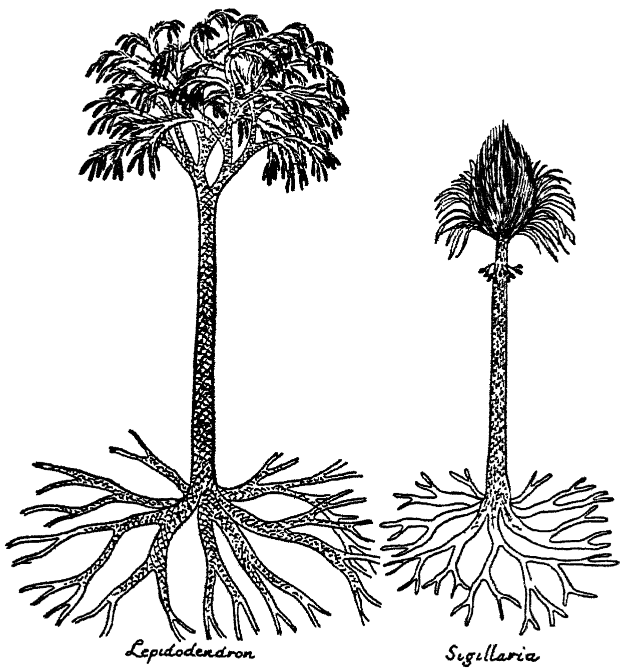

Fig. 133. Reconstruction of fossil Lepidodendron and Sigillaria

the ground. A few species live as attachments on the trunks and branches of tropical trees. The exposed shoots of some evergreen species are used as Christmas decorations. These plants are termed club mosses because their spore-bearing leaves are folded into club-shaped, cone-like structures.

Lycopods

The genus Lycopodium, the members of which are commonly known as "ground pines," is the only very common present-day living group of offspring that have descended from the ancient tree club mosses.

There are over a hundred species living in the temperate zones and in the tropics. Those that live on the ground have horizontal branching stems that creep on or just below the surface of the earth. The inner structure of the stems of these plants is unique (Fig. 134). These are the only known vascular plants that have their wood and phloem tissues arranged in alternate bands within the central cylinders of their stems. The arrangement of the conductive tissues in their stems is very similar to that found within the roots of many vascular plants. It is, therefore, not surprising to find that these are the only plants that show hardly any difference between the inner structures of their stems and roots.

The horizontal underground creeping stems form buds. These buds grow up into exposed erect shoots that are from a fraction of an inch

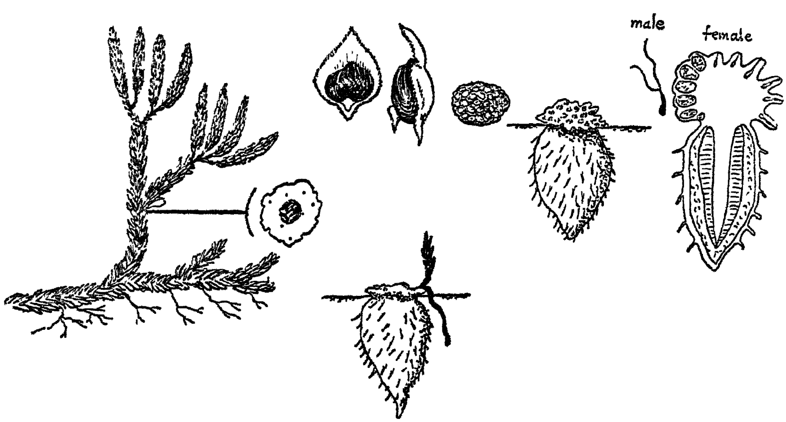

Fig. 134. Reproduction of ground pine (Lycopodium)

to over a foot in height. These creeping stems are often so deep in the ground that the erect branches seem to arise from separate plants. Each erect stem produces bushy side branches that are completely covered with small, dense, crowded leaves arranged in a spiral fashion. The spore-bearing capsules are either attached to ordinary vegetative leaves or are borne within special conelike structures that arise from long leafless stems. All the spores are the same size and contain both male and female characteristics. These are among the most uniform structures formed by nature, and are used to measure very small objects. Some species produce enormous quantities of these tiny spores, which are used by pharmacists to coat pills. They are highly inflammable and were used in former times to make bright flashes of light for taking photographs, for special lighting effects in theaters, and in outdoor fireworks.

When the released spores fall in proper environments they germinate very slowly into tiny, almost invisible growths. It takes from six to seven years for a ground-pine spore to germinate, and only after a further period of twelve to fifteen years is the gametophyte growth able to produce the male and female organs. In some species the prothallus gametophyte growths lie on the surface of the ground and are green. In others they work their way into the ground and either form associations with various fungus growths or live as saprophytes. Some ground pines are also able to reproduce themselves by vegetative means by forming small budlike bodies near the stem tips. These drop to the ground and germinate directly into sporophyte plants.

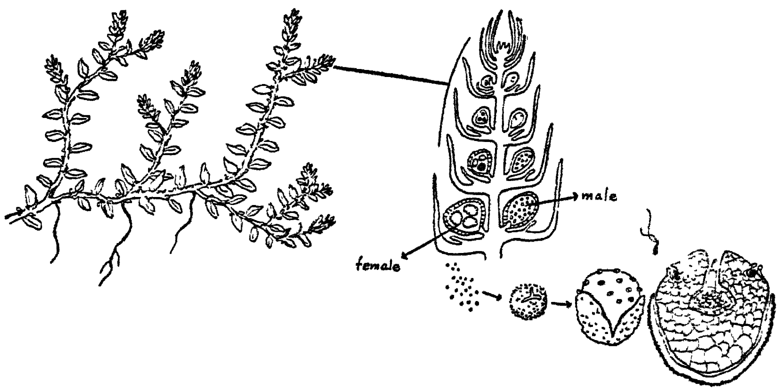

Fig. 135. Reproduction of spike moss (Selaginella)

The spike mosses (Selaginella) compose another large group of living lycopods (Fig. 135). There are about five hundred species in this genus. As they are more delicate in structure than the ground pines, most spike mosses reach their highest development in warm moist lands. Some species are very small and mosslike in their habits. Those that live as attachments on trees may have large flattened green stems several yards in length. The bird's-nest moss grows in places where it endures drought for months, sometimes even years, when it folds its shoots together into a small round dry ball. When rains occur, it absorbs water and unrolls by expanding its stems and leaves again. Such plants that come to life after being apparently dead are called resurrection plants. Many are kept in a dry state as curiosities to be resurrected on certain occasions. Another common resurrection plant is the rose of Jericho (Anastatica), which is a member of the mustard family. This type of resurrection plant and several other kinds that are used for the same purpose are not alive, but unfold and seem to come to life when placed in water, even after they are dead.

The leaves of the spike mosses are arranged in four rows along the stems, two rows being made up of large leaves, and two of small ones. On the upper surface of each leaf, near its base, there is a small scale-like structure that seems to be useless. This type of growth is probably the degenerated remains of some sort of useful structure that the ancient ancestors of these plants possessed. Many animals and plants continue to have various growths of such a useless nature for many hundreds of generations after they have ceased to perform their function. These vestigial structures often help us in determining the ancestry of living and fossil organisms. The woody conductive cylinder of the spike mosses usually consists of separate vascular bundles. Between each bundle and the surrounding body cells there is an open space, and the bundles are suspended in these spaces by special supporting tissues.

Quillworts

The quillworts (Isoetes) are peculiar tufted herbs that live mostly on the bottom of fresh-water lakes and ponds, though a few species may

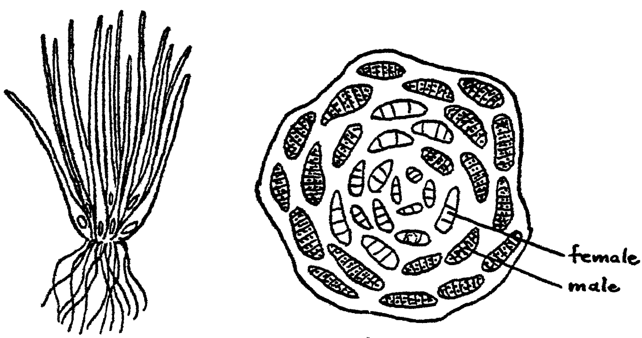

Fig. 136. Quillworts (Isoetes)

grow on wet soils (Fig. 136). The plant consists of long thin unbranched roots and a very short thickened stem, which bears many crowded, very long, quill-like, hollow leaves. All the leaves are usually fruitful, each bearing a single spore case at its base. The outer leaves produce female spore sacs and the inner ones male spore sacs. These peculiar plants are distantly related to the spike mosses, and the existing forms seem to be the descendants of lycopods that lived during the Cretaceous period, about a hundred million years ago.

Horsetail

The small, often inconspicuous present-day horsetail (Equisetum) plants are the sole living remains of a long line of ancestors that first

appeared during the middle of the Devonian period (Fig. 78). The horsetails and all the ancient vascular plants resembling them have been grouped together in the Sphenopsida division of the plant kingdom. These plants have a very long and venerable history and were among the most important coal-forming types of vegetation. They evolved from certain psilophytes, and the many fossils found at varying levels in many parts of the world reveal some of the steps of their evolutionary history. Their development from small beginnings to huge trees, and their eventual decline to the present-day small herblike plants, are perhaps better known than the history of any other group of plants.

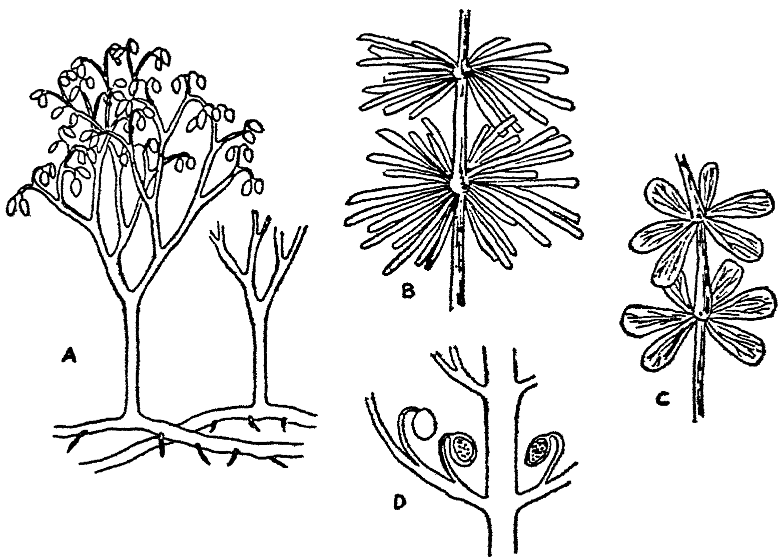

Fig. 137. Reconstruction of fossil horsetail plant ancestors: (a) Hyenia, (b) Asterocalamite Annularia, (c) Sphenophyllum, (d) fruiting bodies of Sphenophyllum

The first recognizable forms found in the fossil state are grouped together within the Articulatae class (Figs. 77-D, 137). The Sphenophyllales were a side branch that appeared during the end of the Devonian period, reached their zenith at the time of the coal age, and completely disappeared during the middle of the Triassic period, about 175 million years ago. The Equisetales were probably the direct ancestors of the present-day horsetails.

One of the most primitive ancestors of the Equisetales was the Hyenia plant, which appeared in the middle of the Devonian period (Fig. 137-A). This was a small plant that had joined stems, many tiny, deeply

lobed, vegetable leaves, and special forked fertile leaves, each of which bore two spore sacs. Groups of three or four fertile leaves formed cone-like fruiting structures at the tips of aerial branches. The Asterocalamites, which appeared during the latter part of the Devonian period, also had joined stems. Their deeply lobed leaves were split in two and arose in whorls from definite nodes.

The Calamites (Fig. 138) formed a very conspicuous part of the land vegetation during the Carboniferous age. These plants had thick, branched underground stems that were well anchored in the soil by many roots. The buds grew into huge tapered aerial trunks that were

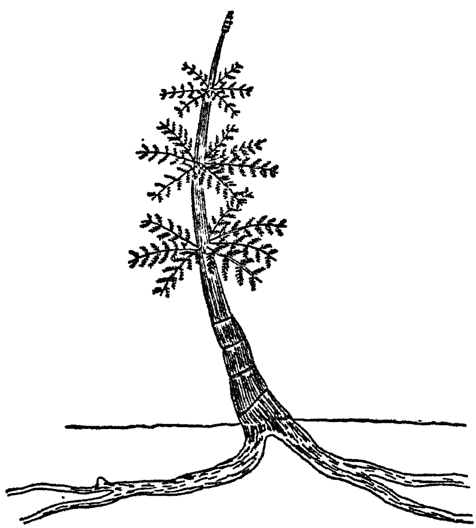

Fig. 138. Reconstruction of a fossil calamite plant

often a hundred feet high, and in some cases five feet thick at the base. The central pith was usually missing, causing the stems to be hollow. They had cambium tissues that formed a continuous layer of wood that was not divided into rings. It is believed that such continuous growth was the result of the changeless mild damp climate prevailing in those ancient days when the year was not divided into seasons of active growth alternating with dormant periods. So many different kinds of reproductive organs have been found that it seems this large group of plants was made up of several families and many genera.

The calamites and other types of ancient vegetation produced spores in such enormous quantities that some coal deposits consist mainly of compressed and changed spores or pollen grains. This type of fuel is called cannel coal. A certain type of cannel coal, commonly known as

jet, is a very clean black substance that is easily cut and polished into many different kinds of beautiful ornaments.

The tree calamites disappeared during the Triassic period and were replaced by several small species that evolved into the present-day horsetails. There is just one genus of these plants in existence, called Equisetum, made up of twenty-five species. Most of these are small plants varying in height from a few inches to three or four feet, but a few species reach heights of thirty feet.

The horsetails are found growing in many tropical countries and are also widely distributed in the temperate zones. The horsetails sometimes grow so profusely among cultivated crops that they become bothersome weeds. They are difficult to eradicate because of their many highly branched underground stems that form many buds and a large quantity of new growth. The underground stems of some species form small potatolike tubers that grow from the nodes and serve as reserves for food.

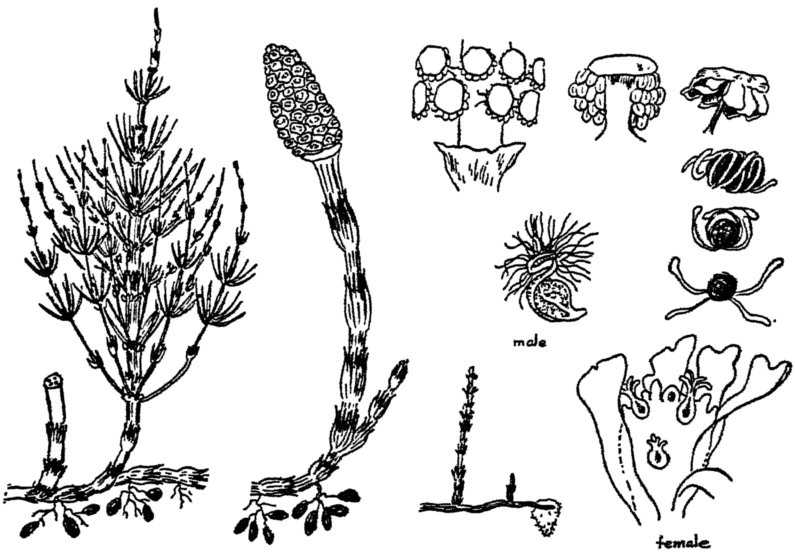

Fig. 139. Reproduction of horsetail (Equisetum)

The exposed aerial stems of the horsetails have a striking appearance, being made up of hollow, ribbed, joined, green stems that arise in whorls from conspicuous nodes. The internode stem sections are loosely attached to the nodes and may be pulled apart with ease. In practically all species the major food-manufacturing activities take place in the stems, which have many green chlorophyll-bearing cells. The stems of the scouring rushes and other species are rich in silicates. These types

of plants were formerly harvested and used in cleaning and polishing metal utensils. Several species are used in medicine.

The horsetails reproduce themselves (Fig. 139) by forming spores that are released from the plant and germinate into very small gametophyte growths that produce sexual organs. After fertilization the zygote grows and eventually develops into the juvenile underground sporophyte stem that produces the aerial branches, while the gametophyte withers away and dies. A very striking feature of horsetail spores is that each one has four elongated spoonlike spiral bands called elators. These are wound around the spore when the atmosphere is damp and unwind themselves and spread out when the air is dry. When the elators are spread out they act as parachutes and aid in distributing the spores by wind. Very often the elators of several spores become entangled together, and the spores are carried by winds in clusters and fall near each other, where they germinate into tiny prothallus growths.

Ferns

The highest structural development achieved by vascular spore-bearing plants resulted in the ferns (Filicales) (Fig. 78). One of the main differences between the ferns and all other spore-bearing vascular plants is in the number of spore sacs. The ferns produce a great number of these on each leaf, while the lycopods usually bear one or two, and the horsetails at the most only ten.

It is believed that the ancestors of our present-day ferns evolved during the Devonian period from broad-stemmed psilophytes. Many

Fig. 140. Primitive ferns and fossil fragment: (a) adder's tongue (Ophioglossum), (b) Marattia, (c) staghorn fern, (d) reconstructed fossil foliage of Clathoptera from Triassic Period

botanists believe that each leaflet of a large compound leaf, or frond, was originally a separate, widened, green, spore-bearing twig of a fern ancestor. It seems that these types of twigs fused together during the course of evolution, and the present-day ferns with their characteristic large leaves slowly evolved.

Fossil remains and impressions of many different kinds of fernlike leaves, stems, spore sacs, and spores are found in many rock formations from the middle of the Devonian period onward (Fig. 140). These kinds of plants were very important coal producers during the Carboniferous age and Middle Life era. It is estimated that about half of all the coal deposited during the coal age was contributed by the ferns and their relatives.

Only a few of the fern families that contributed to those coal deposits now have living representatives. Among those are the royal ferns (Osmundaceae) and the tropical Marattiales. By the middle of the Jurassic period, about 140 million years ago, all the present families of true ferns and their allies had come into existence. One family, composed of the true ferns (Polypodiaceae), has remained widely spread over the earth, while the others have declined steadily in number and species.

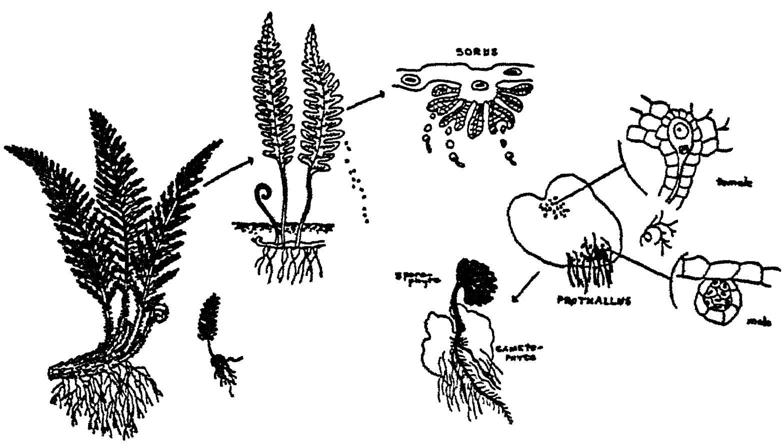

Fig. 141. Life cycle of a polypody fern

Ferns reproduce themselves by spores (Fig. 141). The spore sacs are usually formed on the underside of the green food-manufacturing fronds when they reach a certain state of maturity, but in some species they are borne on special leaves or stalks that do not manufacture food. In most species the spore sacs are bunched together in clusters called sori. There may be many hundreds of such clusters on the underside of a large mature fern leaf.

When the spores are shed, they fall to the ground and under favorable conditions germinate into small heart-shaped gametophyte growths rarely more than a quarter of an inch in width. This prothallus growth eventually forms both male and female structures on its underside. Each female structure forms a single gamete. When the spores of different ferns fall in close proximity and grow into gametophyte plants, the male gamete of one species may fertilize the female of another kind, resulting in hybrids. When a gamete is fertilized, the other female organs die and the single zygote germinates into the sporophyte growth, which eventually forms its own roots, underground stems, nodes, buds, and exposed fronds.

The growth of the fronds is sometimes very slow, requiring three or four years from the time of bud formation until the appearance of the leaf above the ground. The leaves are rolled up in the buds and unfold while growing. The leaves of most species have growing points at their tips, and some may form new leaf cells indefinitely.

Many ferns are able to reproduce themselves asexually either by forming on their leaves small budlike growths that fall to the ground and germinate into new plants when falling in congenial places, or by their underground stems. The rhizomes increase in length from year to year by the growth of their terminal underground growing points. Each year new roots, buds, and aerial shoots arise from the newly formed nodes. The leaves generally die at the end of each growing season. In many cases the older parts of the underground stems die, and the nodes with their fronds and roots, which are on the younger sections, become disconnected and continue their development as separate new plants.

All the known present-day living fernlike plants are grouped into four orders, which are divided into eleven families. These are further subdivided into several hundred genera and over five thousand species. The ferns grow in all parts of the world, but decrease in number and species from the tropics, where they are very abundant, to the polar regions, where only a few species form infrequent widely separated growths. Some ferns are very tiny growths; most have thick underground stems and annual leaves that may reach several feet in height; others are epiphytes and live as attachments on the trunks and branches of trees, while a few are water plants.

The most primitive ferns are grouped together in the Ophioglossales order. Some live as attachments on trees, others in damp and moist places on the ground. A representative species, the adder's-tongue (Ophioglossum) (Fig. 140-A), is a small fleshy plant that yearly forms a new single oval-shaped undivided simple leaf, from one to two inches in height, from which a long stalk grows. At its tip there is a spike about an inch long, bearing two rows of fleshy spore sacs. The Marattiales order (Fig. 140-B) consists of tropical plants that have either thick

underground stems with large coarse leaves or stout aerial stems that resemble the tree ferns. The thick starchy stems of some species are harvested and used as food.

The great majority of ferns are grouped within the Filicales order, which is composed of seven families and about five thousand species. The royal fern, gleichenia, and curly grass families have primitive spore cases (Fig. 142). The royal fern family (Osmundaceae) includes some of our most conspicuous ferns. They are sometimes called flowering ferns because their clusters of spore sacs are arranged on stalks and resemble brown berries of flowering plants. Many members of this family grow in swamps, and some have stems five or more feet high. The Gleichenia family of ferns contains several species that have permanently active growing points at the tips of their leaves. Some of these tropical ferns grow in dense thickets and produce leaves that may be over a hundred feet in length. The curly grass (Schizaeaceae) family is a group of small plants that have twisted grasslike leaves. These plants usually grow on sand at the edges of bogs. Many have forked leaves that continue growth indefinitely and climb over other plants. The stems of these aerial ferns are sometimes very small and inconspicuous.

The filmy fern (Hymenophyllaceae) family is made up of very tiny growths that usually live as attachments on trees. These plants are so small that an entire colony of such ferns may be covered by a single postage stamp. The only truly aquatic plants among the true ferns are grouped in the Ceratopteris family. They either grow as floating plants on the surface of sweet-water ponds and lakes or are rooted underwater in the mud. They are sometimes called horned ferns because their leaves are forked and very curiously shaped. Their leaves are sometimes arranged in rosettes and may be cooked and eaten as greens. These plants are widely grown in aquatic gardens. The tree ferns (Cyatheaceae) resemble palms. They have long aerial stems that are sometimes eighty feet high. In some species the stems are only a few inches in diameter, in others they may be well over a foot in thickness. The terminal growing point forms long leaves that make a beautiful delicate crown on the top of the unbranched trunk. The stem is marked along its entire surface with the scars left by former leaves. The tree ferns are native to warm lands and reach their highest development in the tropical rain forests.

The Polypodium family (Fig. 143) includes the majority of the common ferns. Almost the entire population of ferns growing in the temperate zones consists of these plants. There are over three hundred genera divided into more than a thousand species grouped within this huge family of true ferns. The brake fern (Pteris) is the most widely distributed of all ferns. Its stems are rich in starches and are used as

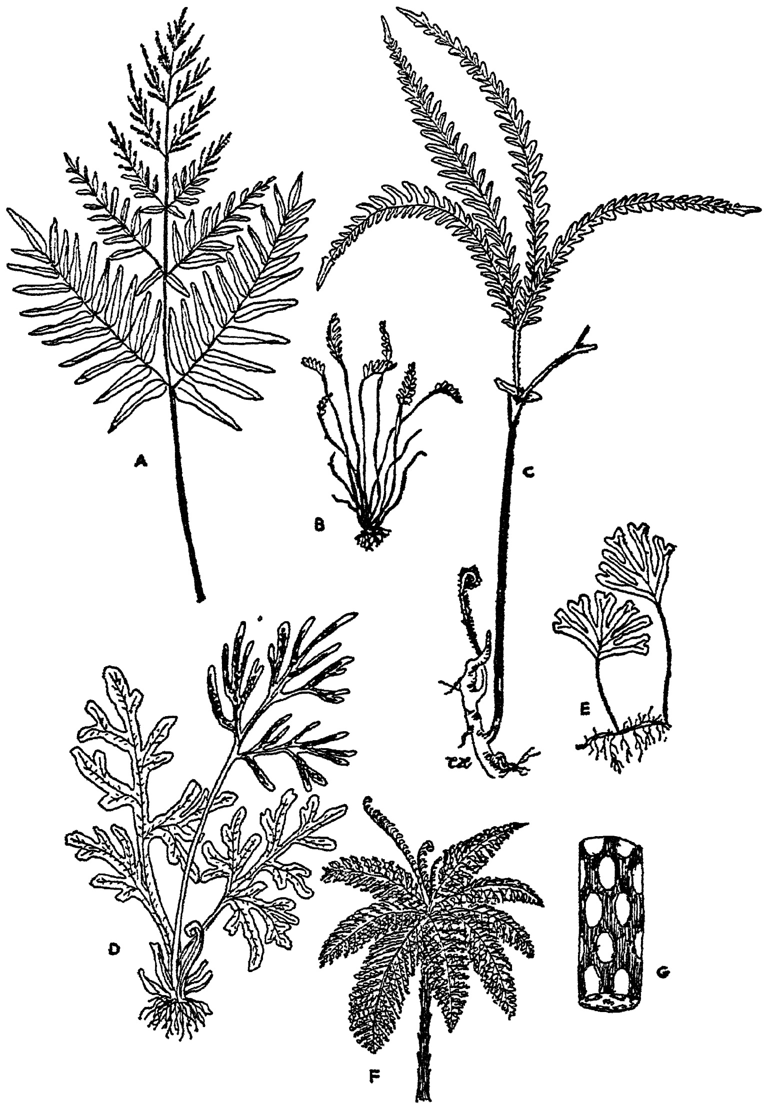

Fig. 142. Ferns: (a) royal fern, (b) curly grass, (c) Gleichenia, (d) horn fern, (e) filmy fern, (f) tree fern, (g) close-up of tree-fern stem

food by both man and animals. The wall ferns (Polypodium) are another very common group. The staghorn fern (Platycerium) forms a curious epiphyte growth on trees. The walking ferns (Camptosorus) are evergreens and propagate themselves by forming tiny new plants at the tips of their leaves. The maidenhair ferns (Adiantum) are the most graceful of our common ferns, having beautiful delicate leaves.

The fourth and last order (Hydropteridales) consists of two families of flowerless water plants that are related to the ferns. (Fig. 144). These are the only present-day living fernlike plants that produce distinctive large female spores and tiny male spores.

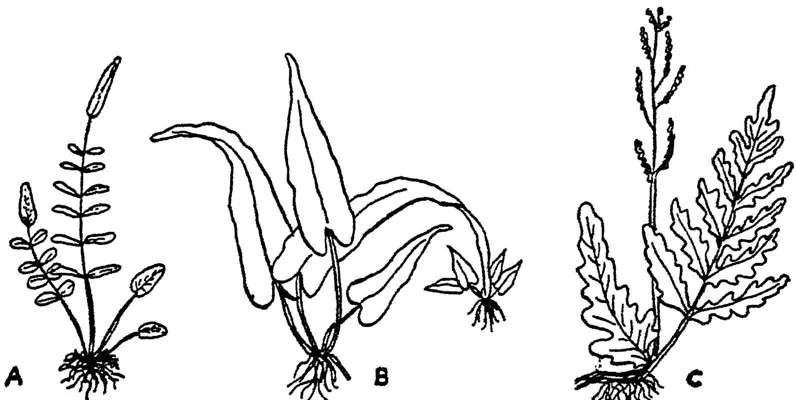

Fig. 143. Some members of the polypody family of ferns: (a) cliff brake, (b) walking fern, (c) sensitive fern

The Marsileaceae family (Fig. 144-A) consists of small creeping perennial plants that are rooted in mud and usually grow along the edges of ponds, where they make a very attractive cover. A typical species, *Marsilea quadrifolia,* has a slender, creeping, branched stem that bears long thin petioles at intervals along its length. The spore sacs are attached to the lower end of these leaf stalks. Each petiole terminates in large leaves that are divided into four cloverlike leaflets.

The Salviniaceae family (Fig. 144-B) consists of two genera of free-floating annual plants. The salvinia is a small plant that has sparingly branched stems that form three leaves at each node. The two upper leaves of each whorl are oval in shape and develop into green floating foliage leaves. The third one is submerged and consists of several threadlike filaments that are densely covered with absorbing hairs that assume the function of roots. The Azolla plants produce slender true roots arising from the underside of their stems.

In some systems of classification the ferns are considered to be inferior plants because they produce their spores on the surface of their foliage leaves. These spores are all similar and germinate into independent prothallus growths that produce both male and female structures on the same gametophyte plant. The flowerless water plants (Hydropteridales), horsetails (Sphenopsida), and the ground pines (Lycopodium) are classified next, as they produce two kinds of spores on special

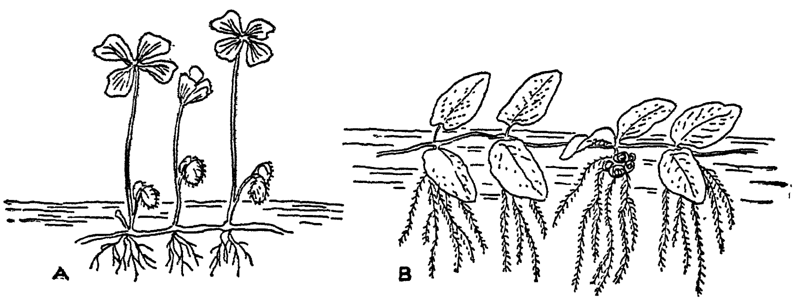

Fig. 144. Water ferns: (a) Marsilia, (b) Salvinia

fertile leaves that have been adapted for the sole purpose of producing and supporting the spore sacs. The spores of these plants germinate into separate independent male and female gametophyte plants. The spike mosses (Selaginella) and the quillworts (Isoetes) are considered to be the highest forms of plant life within the Pteridophyta division, because they retain their female spore sacs, spores, and gametophyte growths until after the gametes have been fertilized and the new young embryo sporophyte plant has attained a certain size and is provided with a store of food that has been supplied by its parent.

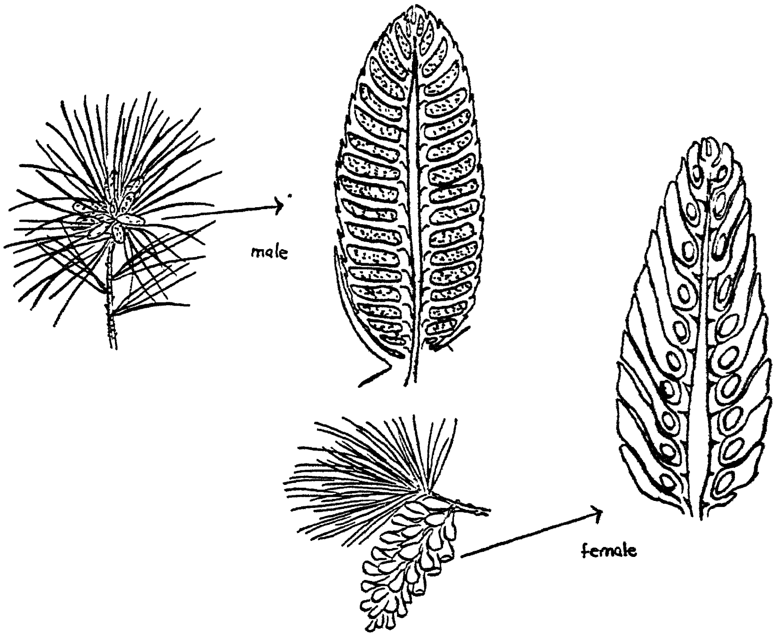

Fig. 145. Gymnosperms—longitudinal sections of pine cones

26. NAKED-SEED PLANTS

THE highest and most successful present-day living plants and animals have two very important features in common. They personally feed and personally protect their young. The more care that parents give to the welfare of their immature young, the more likely it is that that family of plants and animals will be able to survive, thrive, and increase in numbers.

The lowest forms of plant life, and many kinds of fishes and other primitive animals, release their eggs soon after being fertilized. These kinds of zygotes and fertilized eggs are extremely tiny cells that are not well protected by efficient outer coverings, contain very small supplies of reserve food, and germinate into organisms that are forced to take care of themselves from the moment of birth. Those plants, such as the mosses and ferns and their allies, that reproduce themselves by forming independent gametophyte growths from their released spores are at the mercy of many environmental hazards, and must be covered with wa-

ter at the time that their reproductive structures are ripe to ensure the movement of their male gametes to the female organs. All these types of organisms waste innumerable quantities of reproductive units in order to ensure the continuance of their species, because only a few of the billions of spores, zygotes, and eggs produced and liberated ever germinate and grow into mature plants and animals.

The ants, bees, and birds that take care of their eggs and young, and the warm-blooded, milk-producing mammals that develop their eggs internally within special protective tissues, release their offspring as completely formed individuals, and personally feed, shelter, teach, and tend them after birth, are among the most successful present-day living animals, even though they give birth to a relatively small number of progeny.

The highest forms of vegetation retain their female spores, which produce the gametophyte growths and gametes, while attached to and fed by their mother sporophyte parents. The fertilized female eggs grow into tiny, partially developed new sporophyte plants, called embryos, which are supplied with stores of rich food and protected by coats in seeds before they are shed.

The gymnosperms (Fig. 78), which is a name that comes from a Greek word meaning naked seeds, are woody plants that bear their ovules, which change into seeds, on the surface of special reproductive leaves. These scale- or flaplike fertile structures are usually arranged in a spiral fashion around short stems to form cones. A cone consists of anywhere from a few to a hundred or more of such flaps. In most species the male leaves, and the female leaves, are borne on separate cones, respectively called pollen cones and seed cones. In many species both types of cones are produced by the same plants; in others they are borne by separate male and female individuals. In the highest orders of gymnosperms the male and female structures are combined within single flowerlike organs.

One of the most significant features of all land-growing seed plants is that the transfer of their male gametes to their female organs is independent of rainfall. Unlike all lower forms of plant life, which form independent gametophyte plants, the seed-bearing plants enclose their male gametophyte growths and gametes within well-protected dormant pollen grains that are carried by winds, insects, birds, and other means. The transfer of pollen, an action that is called pollination, is not dependent upon a water cover, and can take place under many different kinds of atmospheric conditions. As soon as a male gamete fuses with a female gamete, the double number of chromosomes is restored. Although several female gametes may have been fertilized, usually only one continues growth while the others shrivel up and die. The initial fertilized cell or zygote of the sporophyte generation divides and redivides again

and again until a complete embryo is formed. This embryo is made up of one, two, or several rudimentary leaves, which are called cotyledons, a stem section, a growing point that will develop into the shoot system, and an elongated lower end, called the radicle, which will later develop into the primary root system. When all the changes in the ovule have been completed, the entire seed, which consists of the embryo, stored food, and protective coverings, becomes dormant and is ready to be shed.

The time that it takes for a seed to be formed varies greatly in different species. The gingko trees are pollinated and fertilized and ripen their seeds within several months. It takes three years for a female ovule of a pine tree to develop into a seed.

Seeds are not all alike. There are all gradations from female ovules that have just been fertilized to germinated sporophyte plants with exposed stems, leaves, and roots that are fully developed before being shed from the parent plant. When the embryos of most kinds of seed plants have attained a certain degree of development, which is different and characteristic of each species, water is removed, their growth is stopped, and the seeds become dormant. While the seeds are in a dormant condition they are released from their parents and dispersed by winds, water, animals, humans, and other means. After they are deposited in suitable places they may remain alive and dormant for varying periods—several days or months, in many cases from three to ten years, and in a few instances up to about two hundred years, depending upon the species—until proper habitat, temperatures, moisture, and other conditions prevail. When all the requirements for growth are satisfied, the seeds absorb water, swell, and germinate by continuing their arrested growth, exposing their stems and leaves to the air, and sending their roots down into the earth. They derive their initial nourishment from the stored food in the endosperm that was provided by their parents. When their absorbing and food-manufacturing organs have sufficiently developed they continue growth as independent plants.

The formation of seeds originated very early in the history of vascular plants, and their early evolution is hidden in obscurity. The only fact that is definitely known about the origin of seed formation is that the earliest recognizable fossils of ovulelike structures have been uncovered from coal formations that were deposited about 425 million years ago, sometime during the middle of the Devonian period.

Although scores of different kinds of stems, vegetative leaves, reproductive leaves, cones, spore cases, spores, ovules, and seeds of primitive seed plants have been uncovered from deposits laid down during the upper Devonian and subsequent periods, it is very difficult, and in most cases practically impossible, to reconstruct complete individuals, species, and genera, as the various organs and structures are seldom found

attached together. From the study of the thousands of detached and separated parts that have been found it is evident that there were many different kinds of seed-bearing plants in those ancient days.

One of the typical and best-known reconstructed early seed-bearing plants has been named *Lyginopteris oldhamia* (Fig. 146). This was a small vinelike climbing plant. The internal structure of the stem was somewhat like that of some of our present-day conifers, but never reached a width of more than two inches. The foliage was made up of beautiful delicate lacelike fronds. The seeds were complicated structures, each having an internal strand of vascular conductive cells. Each seed was enclosed within an open, eight-lobed, cuplike structure that had many spherical oil glands scattered over its surface.

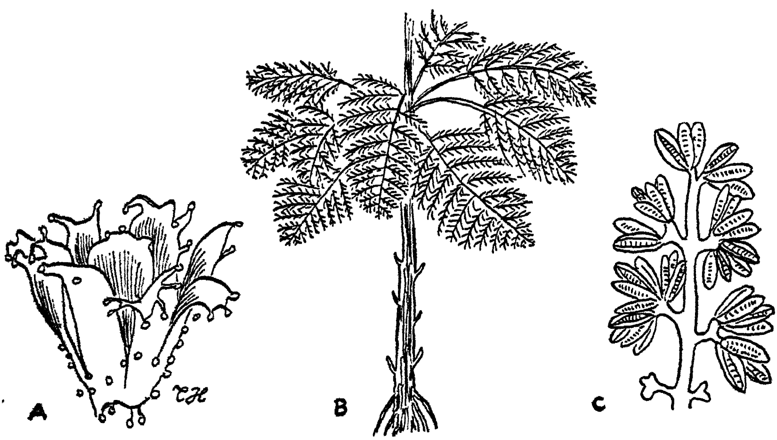

Fig. 146. Reconstruction of fossil pteridosperms: (a) Lyginopteris seed pod, (b) *Lyginopteris oldhamia,* (c) Caytonia

The early seed bearers formed an important constituent of the land vegetation during the latter part of the Devonian period, and maintained their prominence right through the Carboniferous, Permian, and Triassic periods. They disappeared sometime during the middle of the Jurassic period about 140 million years ago when the true gymnosperms were the dominating plants that replaced them.

The true gymnosperms arose from the earliest seed bearers and evolved in several directions (Fig. 78). The most important member of one of the earliest groups known only through its fossil remains was composed of a tall tree of the order Cordaitales which disappeared during the Triassic period. The most primitive present-day living series, Cycadophyta, includes the Cycadales and their ancient ancestors; the Glossopteris flora, which was widely spread throughout the cold Gond-

wana land of the Southern Hemisphere; and the Cycadeoidea or Bennettitales, which were among the most important coal-forming plants growing in the Northern Hemisphere during the Middle Life era. The only important present-day living group embraces the conifers and the maidenhair trees (Ginkgoales). Fossil remains of several more groups of naked-seed plants have been uncovered in many parts of the world from various rock formations, the classification of which is still in doubt. A recent group of gymnosperms, called Gnetales, appeared very late in geological time.

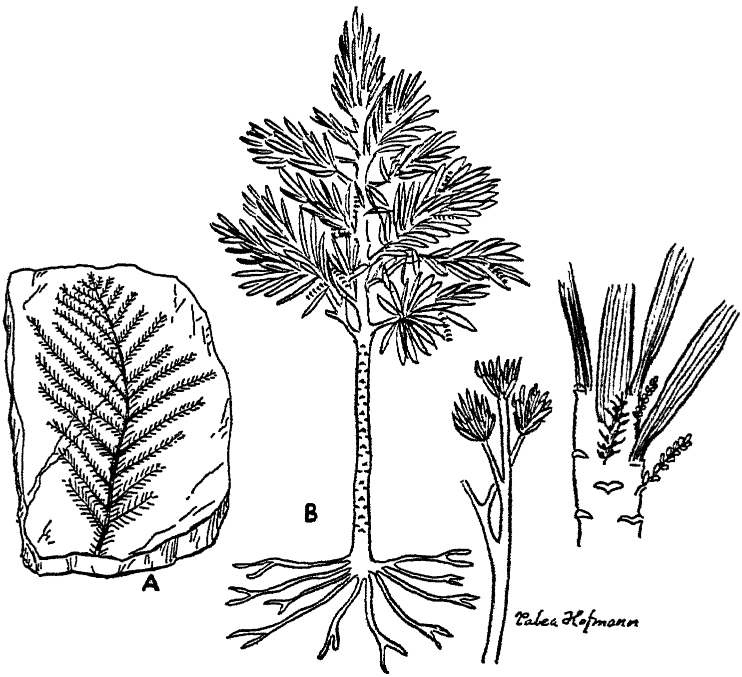

Fig. 147. Reconstruction of fossil seed-bearing plants: (a) Walchia, (b) Cordaitales

One of the best-preserved and best-known orders of ancient true gymnosperms were the Cordaitales, which arose sometime during the Devonian period (Fig. 147). This important group of naked-seed plants was composed of several families and many species that were among the most widely spread and tallest trees growing throughout the North Atlantic continent and Angara Land during the Carboniferous period. When the ice cover began to move northward during the Permian period these lofty trees started to die, and before the middle of the Triassic

period, about 270 million years ago, they completely disappeared. It seems that the Cordaites were among the earliest true gymnosperms to appear, and the first to be killed by climatic changes.

The cordaitales were tall trees that thrived in warm moist localities. They often reached heights of over a hundred feet with stems that sometimes were over three feet in diameter at the base. The trunks were branched only near the summits. The smaller branches and twigs were densely covered with leaves. The foliage ranged in different species from tiny scales to long straplike leaves three or more feet in length.

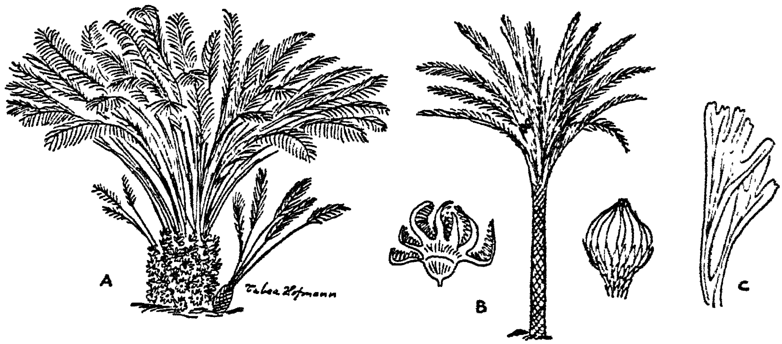

Fig. 148. Reconstruction of fossil cycads and fossil fragment of ginkgo leaf: (a) Bennettitales, (b) Williamsoniella with two female fruiting bodies, (c) fossil of ancient ginkgo leaf

27. VENERABLE CYCADS AND IDOLIZED GINKGOS

THE most primitive present-day living naked-seed plants are called Cycadales, which comes from a Greek word meaning palm, because they resemble palms in their growing habits. A few have fernlike fronds, others palmlike leaves, and the stems of many resemble those of the tree ferns. The cycads are extremely long-lived, very slow-growing plants, and many reach an age of well over a thousand years. Another characteristic feature is that their male sperms are the largest male gametes found in the entire living world. In no other individuals of the plant or animal kingdoms are the male sperms large enough to be visible as tiny specks to the unaided eye.

Cycads

The Cycadophyta first appeared sometime during the Carboniferous period, about 350 million years ago (Fig. 78). These curious woody, primitive, seed-bearing evergreen plants were so numerous and widely spread throughout the Middle Life (Mesozoic) era that this span of geological time, when the dinosaurs were at their zenith, is known to botanists as the "Age of Cycads." One of them, called the Caytonia (Fig. 146), is the earliest ovary-bearing plant so far discovered. Fossil remains of that ancient vinelike plant have been found in sedimentary rocks deposited about 155 million years ago, at the beginning of the Jurassic period. The Glossopteris flora migrated northward during the

Permian period, became intermingled with the Northern Hemisphere plant life, and eventually died out. During the latter part of the Cretaceous period, about 75 million years ago, the conifers became the dominating plants and started to replace the remaining cycad plants. The Bennettitales disappeared about 10 million years later, and today there are left only about one hundred species of Cycadales, grouped into nine genera. These few remaining members of a formerly vast world-wide vegetation are restricted to a few widely scattered tropical and subtropical localities. The most common and representative genera are the treelike cycas, which give the entire series its name, and the zamias, which have large tuberous underground stems.

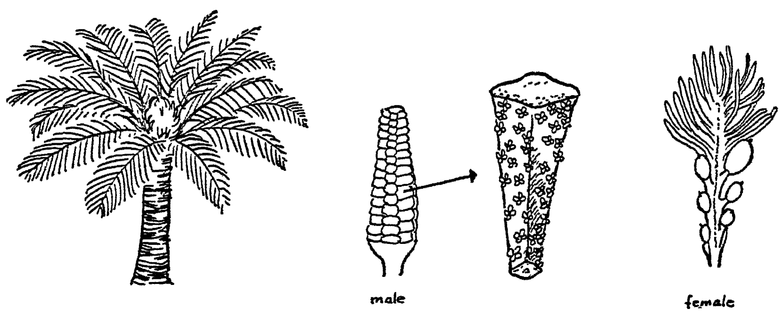

Fig. 149. Cycas

The cycas (Fig. 149) are usually tall palmlike trees that reach heights up to thirty feet. Together with the zamias and a few other cycads, they are among the most popular ornamental plants grown in tropical and subtropical gardens and in conservatories in temperate zones. The cycas is sometimes erroneously called "sago palm," but is in no way related to the true sago palms of commerce (*Metroxylon sagu*), which are flowering monocot plants. The thick columnar cylindrical stems of cycas are seldom branched and resemble the trunks of tree ferns. The outer coverings consist of scars and other remains of fallen leaves. Internally all cycads contain little wood, but are filled with a soft gummy substance. Cycas gum, which is extracted from some species, is an article of commerce that resembles gum arabic. The internal central pith is very rich in starch, which is extracted and used as a food by many natives in warm lands. The terminal growing point is in the form of a bud that seldom produces branches. When young, the foliage is rolled up and resembles the fronds of ferns. The long fern- or palmlike leaves unroll to form a luxurious, striking, wide-spreading crown. The beautiful glossy palmlike foliage of some species has been used as decoration for burial and other religious ceremonies by all faiths having access to these plants

since the dawn of civilization. Many species bear red berrylike fruits in cones that ripen during Christmastime. The seeds are poisonous when ripe, but may be made harmless by soaking in water for many days, and by other means. When properly processed, these cycas nuts have a delicious chestnutlike flavor that is highly esteemed by people in many tropical and subtropical countries.

The fruiting structures of all the Cycadales are on separate male and female plants. The female structures of cycas are not arranged in close compact cones but are modified fernlike leaves that bear round exposed ovules along their edges (Fig. 149). The small brown or reddish female carpels are about eight inches long and are intermingled with the green foliage leaves in the crown. The male spore sacs, which produce the pollen grains, are borne on elongated wedge-shaped stamens. These scalelike modified reproductive leaves are tightly packed around special terminal stems to form cones. Each male plant bears anywhere from one to a hundred or more very uniform cones every season. The number of cones formed depends upon the species.

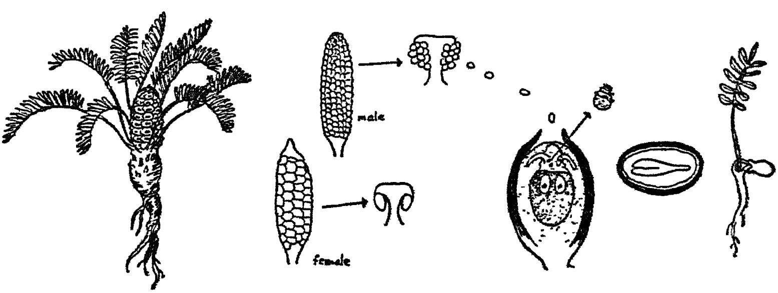

Fig. 150. Sexual reproduction of Florida arrowroot (Zamia)

The Zamia plants (Fig. 150) and their allies have large, thick, tuberous underground stems that resemble huge carrots. The Florida arrowroot (*Zamia floridana*) produces a large amount of starch, which is stored in its thickened underground stem. The short cylindrical exposed part of the stem is terminated by a single growing point that never divides to form branches. The growing point is in the form of a bud that produces the large graceful leaves that remain attached for several years, and from time to time, after a plant has reached maturity, forms the reproductive cones. The male and female Zamia plants produce several small male and female cones, but a few related female Cycad plants have a single enormous female cone. The cones of both the male and female plants are made up of small disk-shaped structures. These are attached by short stems to the cones, and resemble the reproductive modified leaves of the horsetails. Each female disk bears two exposed ovules

on its undersurface. The male stamens form large numbers of round male spore sacs, which produce and liberate innumerable pollen grains.

Bennettitales

The Bennettitales (Cycadeoidea) were a huge group of naked-seed plants that evolved from the cycads sometime during the latter part of the Carboniferous period and disappeared at the end of the Middle Life era, after having dominated the vegetable cover of the world for a period of more than 120 million years. Many Bennettitales had short thick exposed stems and huge tuberous underground stems. These species had palm- or fernlike foliage and resembled the Zamia plants of

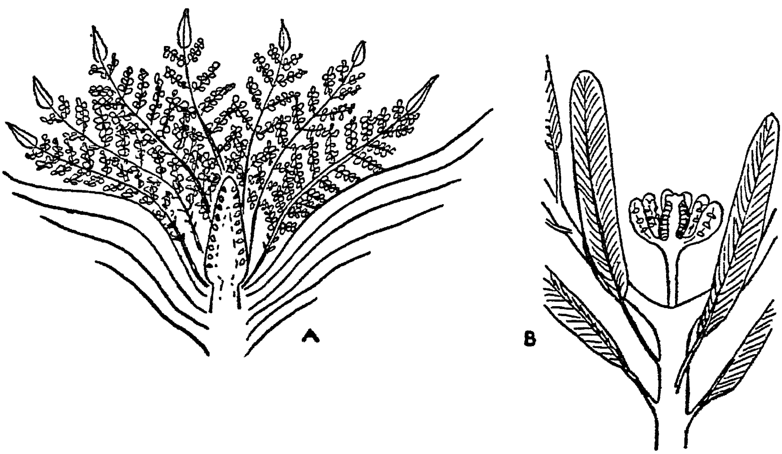

Fig. 151. Reconstruction of fossil Bennettitales plants: (a) Cycadeoiea, (b) Williamsoniella

today (Figs. 148, 151). Others were very slender plants that had several trailing or climbing stems. The Bennettitales reproduced themselves by special modified structures that were formed on lateral side branches, in contrast to the terminal cones of the cycads. These flowerlike reproductive structures resembled, to a marked degree, the true flowers of magnolia plants, and some botanists believe that those primitive flowering plants may have evolved from the Bennettitales.

Ginkgo

The maidenhair trees (*Ginkgo biloba*) (Fig. 78) are the sole remaining representatives of a formerly large group of naked-seed plants that arose during the Carboniferous period. The ancestors of these beautiful shade trees, collectively called ginkgophytes, are known only by their leaves, as those are the only organs that have remained well preserved

as fossils (Fig. 148). The ginkgophytes were very numerous and widely spread in many parts of the world throughout the Middle Life era and the Tertiary period. They started to die during the Quaternary Ice Age, and today there is only a single species left (Fig. 152). Until recently it was thought that there were no wild maidenhair trees on earth, but some years ago a few uncultivated natural-growing trees were discovered in China and Japan. All the ginkgoes found in the parks and gardens and along the streets of many subtropical and Temperate Zone cities all over the world have been introduced to those places from nursery stock that originally came from Chinese temple gardens.

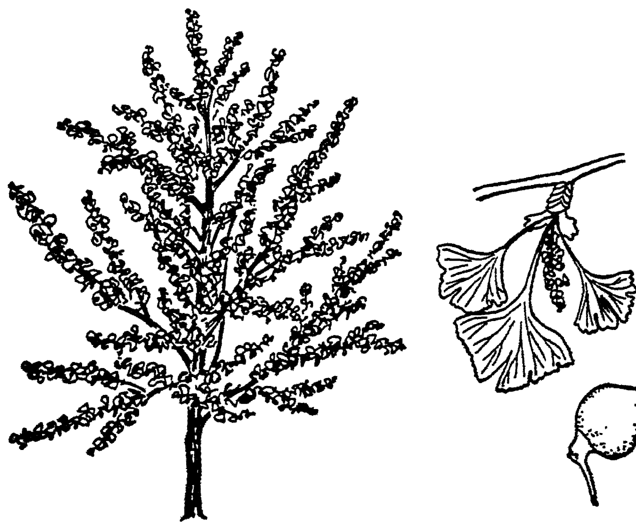

Fig. 152. Maiden hair tree (ginkgo)

Maidenhair trees have been cultivated in Chinese monasteries for thousands of years, and were among the first trees to be used for religious purposes. During the course of human history many different kinds of plants have been considered sacred because they were thought to possess special powers of perception, passion, and reason. Others were revered because they resembled the sun; had curative values; supplied man with food, clothing, and shelter; furnished him with colors, spices, and attractive odors; were thought to be immortal; were extraordinarily fruitful and strong; were believed to harbor a spirit or represent some deity. Among the hundreds of different kinds of trees that were worshiped in ancient times and are still adored by certain primitive tribes are the acacia, apple, ash, baobab, beech, birch, boxwood, camphor, cedar, cherry, citron, cypress, date, elm, ethrog, fig, fir,

frankincense, laurel, lemon, linden, locust, mango, oak, orange, olive, pomegranate, tamarisk, walnut, and willow trees. Other plants that have been revered or are still part of the folklore of many people in different lands are clover, corn, grape, iris, leek, lily, lotus, mandrake, mint, mistletoe, myrtle, narcissus, onion, rice, rose, sunflower, and wheat plants.

Many plants that bear their leaves, branches, flowers, and fruits in series of threes have been considered sacred in different parts of the world since antiquity. One of the most revered plants was the so-called "shamrock," which is no specific plant but a name given to any species whose compound leaf is divided into three leaflets. Some of the most common "shamrock" plants are clover, hop, wood sorrel, and black medic. When a four-leafed "shamrock" compound leaf is found, it is considered to be a lucky omen.

Many cults believed that their sacred plants were guarded by special terrifying monsters, demons, and spirits, or were inhabited by angels, dryads, nymphs, pixies, and other mythical beings. In many cases it was forbidden, on the pain of death, to gather any part of a sacred plant, to cut and harm it in any way, or even to touch it. In some other faiths the high priests only were permitted to approach the holy plants during special ceremonies. Today the people of most faiths use the boughs, leaves, flowers, fruits, or entire plants for special religious purposes, and on other significant occasions. Since time immemorial artists have used plants and plant parts as symbols in decorating homes, public buildings, and temples, as well as on clothing, coins, stamps, columns, furniture, paintings, and sculpture.

The ginkgoes have several features in common with the cycads. Both of these orders of plant life bear their reproductive structures on separate male and female individuals, their male gametes are self-propelling sperms that swim through a liquid-filled pollen chamber in the ovule to reach the female gametes, and both types of vegetation consist of exceedingly long-lived plants. In all other respects the cycads and ginkgoes differ widely. The internal woody structure of the ginkgoes is similar to that of the conifers, and for this reason some botanists believe that the ginkgoes and conifers evolved from the Cordaitales. But the habit of growth, foliage, and reproductive organs are different. The ginkgoes are deciduous trees that renew their flat fan-shaped leaves annually, while the conifers are usually evergreens that have elongated needlelike or tiny scalelike foliage.

The maidenhair trees grow to be from sixty to eighty feet high. When young the single trunk supports many branches of different lengths, giving the tree a curious irregular shape. On aging the plant assumes a wide pyramid form. These trees make excellent ornamental park and garden specimens and are highly prized as street trees because

they are long-lived, thrive under many different kinds of climatic conditions, are immune to insect and disease attacks, are resistant to storms, seldom being broken or uprooted by heavy winds, and can withstand the dust, smoke, and gasoline fumes of our modern cities.

The male trees produce their pollen grains in spherical spore sacs that are arranged on long thin stalks to form catkinlike clusters. The female plants have short stubby stalks that usually support two ovules each, but some trees may bear several ovules on each stalk. Generally, only one ovule on each stalk matures into a delicious hard nut that is highly esteemed by Orientals. The nut is enclosed within a fleshy, soft, cherry-like pulp that has a vile odor. As these unpleasant fruits disfigure lawns, gardens, and sidewalks with unsightly, slippery, and dangerous skin and pulp, only male trees should be used in planting.

Fig. 153. Conifers and gnetales: (a) Welwitschia, (b) Gnetum, (c) Ephedra

28. BORDERLINE CONIFERS AND DESERT GNETALES

The most successful, widely spread, and important present-day living naked-seed plants are the conifers. These are the typical, mostly evergreen, resinous softwood trees and shrubs of cool and some arid lands. Many form the borderline vegetation at the snow line of high mountain peaks and at the north arctic, where they penetrate well into the polar regions. The pines, firs, hemlocks, spruces, larches, cedars, yews, and cypresses are abundant in all Northern Hemisphere cool-climate zones, where they usually grow by themselves. In the middle temperate regions they grow in mixed associations together with the broad-leafed hardwood deciduous trees. Certain pines, cypresses, cedars, larches, and other conifers are a familiar part of the landscape of Mediterranean and many other subtropical and warm Temperate Zone lands, as they are able to grow on poor soils and under low moisture conditions where the hardwoods are unable to compete. The araucarias and podocarps are typical Southern Hemisphere conifers.

The conifers arose sometime during the Carboniferous period, either directly from the Cordaitales or from some other similar type of plant life (Fig. 78). In the upper Carboniferous deposits there are found many fossil remains of a conifer plant that closely resembled the present-day monkey puzzle tree. Another early conifer that was very prominent during the Permian and Triassic periods was the voltzia, which had the needlelike foliage of some of our pines. They became modernized during the Jurassic period, and by the beginning of the Quaternary Ice Age the conifers were the dominating plants of the world, many being giant trees over three hundred feet in height. Fossil remains of many huge redwoods were uncovered in France long before the few

present-day living remnants of that former vast vegetation were discovered growing in certain restricted areas of central California. Practically all of the gigantic conifers were killed off by the advancing cold wave and ice, and only those species that were able to withstand frost survived.

About ten thousand years ago when primitive man was just starting to develop his agriculture, tremendous stands of pure conifer and mixed forests covered a great part of the Northern Hemisphere. This tremendously rich heritage was of the greatest importance and of utmost service to mankind. Civilization is a direct result of the many benefits man derived from his forests, and it would have been impossible to achieve without trees. The primeval forests supplied early man with food, shelter, fuel, medicines, spices, building materials, furniture, weapons, tools, utensils, posts, poles, fences, colors, and meat, hides, fur, and fish. His first boat was a hollow trunk, and his original wheel a round log.

When humans increased in numbers and started to migrate from place to place, they found the forests to be surmountable barriers that they had to clear in order to grow their cultivated food and industrial crops. During the past two thousand years man indiscriminately cut and burned a large percentage of the forests where he made his home, believing that his supply of wood was inexhaustible. Enormous quantities of lumber were changed into structural supports for mines, buildings, bridges, and ships. The wood used in the manufacture of vehicles, coke, lamp black, railroad ties, veneer, plywood, boxes, crates, barrels, shingles, and matches represents thousands of square miles of forest areas. Man learned how to make paper from wood pulp; soften hard hides into soft leather by the use of wood tannins; extract fibers, cork, and bark; tap many different kinds of trees and convert the saps into sugar, chicle, pitch, gum, mucilage, resins, and turpentine.

The advances made in the science of chemistry during the past fifty years have enabled chemists to rearrange the atomic structures of many organic compounds, and to change leaves, fruits, bark, bast, wood, internal juices, and other natural plant products into composition building materials, stuffing and insulating matter, alcohols, synthetic foods, drugs, perfumes, essences, colors, and textiles, many kinds of oils, resins, tars, turpentines, rosins, rubber, plastics, and innumerable other valuable commodities.

It is only recently that man has started to realize that he was criminally devastating and wasting his forest resources, which are vital to him. Forests prevent floods and harmful soil erosion. They purify the air during daylight hours by releasing large amounts of oxygen, and many conifers have the added virtue of liberating pleasant curative resinous materials into the air that are beneficial to people, especially those suffering from lung and other ailments. Forests have a cooling

effect in warm climates and moisten the air in dry regions. Many absorb and evaporate such huge quantities of water that they are used in draining swamps. Forests support a vast population of wild animal life and are delightful recreation resorts. Trees in city streets and in parks and gardens give shade and protection against winds, enhance the physical appearance of places, and increase the value of property.

Today forests are being conserved and economically exploited by federal, state, and community governments, or by private concerns under direct governmental supervision. Large areas of poor, exposed, and otherwise unproductive lands are being planted with new kinds of scientifically bred trees that are immune to insect and disease attacks, are able to grow under many different kinds of climatic and habitat conditions, and have the ability to capture and combine the energy from the sun, the waters of the world, the gases of the air, and the minerals from the earth into large quantities of new and better kinds of raw materials for man's new chemical industries.

The conservation of existing stands; proper insect and disease control measures; prevention and control of fires; reforestation of otherwise unproductive and exposed lands with suitable varieties; protecting and thinning young trees that may be sold as fuel, Christmas trees, poles, and for other purposes; properly tapping only healthy mature sap-yielding trees; restraining criminally harmful and wasteful cutting practices; leaving special desirable specimens for natural reseeding purposes; stacking or carting away the small branches and other remains after cutting; managing forests as regular agricultural crops that are renewed as mature trees are cut; and the preservation and protection of wild animal life—these are some of the main activities of modern foresters.

The conifers are usually tall, stately trees that have a single tapering trunk supporting many side branches. Those that live at the extreme limits of vegetation beyond the tree line are often very small shrubs, and in extreme cases may even appear to be tiny herblike growths only two inches in height. Some species are artificially restricted in growth for use as indoor decorative pot plants, and a few kinds are pruned into low hedges or trimmed to assume various shapes for landscaping purposes.

A typical conifer tree, as a rule, undergoes three distinct changes in appearance during its lifetime. Throughout its initial ten to twenty years, or juvenile stage, the young tree is usually in the form of a perfect symmetrical pyramid that is screened by a beautiful dense cover of green or blue foliage, which often completely hides the main stem and all but the tips of the side branches, which arise from the level of the ground and gradually taper upward to a single terminal bud. When the

tree approaches maturity the lower branches start to die out, and there is a period of unshapeliness that lasts for several years. During this stage many unsightly dead branches are shed, and the remaining stubs are covered with new growth. These covered stubs are the knots that are found in the inner heartwood of old trees. The new wood that is formed after all the dead branches have fallen is clear of knots and imperfections. When mature the straight cylindrical trunk bears its branches some distance from the ground. In many of the tallest conifers the lowest branch, after this mature stage has been reached, may be as high as a hundred feet above the ground. The remaining lofty leaf-bearing branches may either retain their long pyramidlike form or assume the shape of a very attractive, shade-giving, wide-spreading, umbrellalike crown.

The foliage generally consists of long, thin, needlelike leaves that are sometimes attached in clusters of two or more to short stubs, or are small, usually flat, scalelike structures that cover the young twigs. Some tropical conifers have wide, flat, ginkgolike leaves. The leaves usually remain on the trees from three to ten years, and as new ones are formed yearly as old leaves are shed, most conifers are evergreen. The larches and some bald cypresses are exceptions; they renew all their foliage annually. The small compact form of the leaves is a great advantage to the conifers, as they are not broken by heavy snows, resist the force of strong winds, and present a small evaporating surface. In a careful leaf count that was made of many pine trees it was found that an average one-year-old seedling has about 75 leaves, by the fifth year it has 2,300, in its tenth year 16,000, six years later 2,340,000, and when mature over 7,000,000 leaves, which would cover a flat surface of more than thirty-two square miles. In contrast a large maple tree has over a million leaves, each of which has as much surface area as eight hundred to fifteen hundred pine needles.

The leaves, cones, stems, and roots of practically all conifers, with the exception of the sequoias and larches, contain a great deal of resin, which makes them unpalatable to animals, covers wounds, protects the trees against many insects and diseases, and coats the leaves with a thin film that prohibits excess loss of water. The resinous quality of the leaves, which sometimes also contain large amounts of silicates, makes them so resistant to decay that the shed foliage may remain intact on the ground for many years, and this accumulation is often so thick that it prevents the growth of any other form of plant life on the forest floor.

Under certain conditions resin remains intact indefinitely and large deposits of fossilized resin, which are known as amber, have been found in the form of hard, brittle yellow or brown nodules in Holland, England, East Prussia, and other Baltic countries, and in Rumania, Sicily, and Burma. Amber is mined and cut into decorative ornaments, cigar,

pipe, and cigarette holders, and other small objects. Embedded among the fossil remains of ancient conifers bits of leaves, spores, pollen grains, eggs, insects, and other small plant and animal matter have been found to be so perfectly preserved in amber that the cellular structure of those organisms is as clear and distinct as the day they happened to be covered with resin many millions of years ago.

The preservative qualities of turpentine and other resin products are so efficient that they are used together with certain oils and lead to cover metal, wood, and other surfaces with a protective film that is resistant to rust and decay. Various resins are naturally changed into a great variety of hard substances called dammars. These are well adapted for varnishing paper.

The fresh and fossilized hard resins of certain tropical and subtropical trees sometimes become transformed into various kinds of colorless, transparent, bright yellow, red, or brown substances that are called copals. When dissolved in alcohol these copals become converted into various kinds of varnishes. The cheaper kinds of copals are obtained directly from trees, or are found at their roots or near the surface of the ground. The true copals that yield the best kinds of varnishes are found as fossils embedded in the earth. They range in size from small granules that weigh a few ounces to huge lumps that weigh one hundred or more pounds. Lacquer is a natural varnish that is extracted from the lacquer tree. When it leaves the tree it is a milky fluid, which darkens and thickens rapidly on exposure.

The wood of the stems and roots of conifer trees has a relatively simple structure, being made up of hardened body cells and simple wood cells that also act as strengthening tissues. The tracheid wood cells are relatively short, narrow at the ends, and pitted with many circular disks. There are no complicated long vessels, special fibrous supporting cells, or air pores. The living downward food-conductive cells are not supported by any companion cells. Among the wood tissues are many resin-secreting cells and resin ducts that connect into a canal system. This type of structure, known as softwood, has a more uniform structure than the hardwood of the deciduous broad-leafed trees such as the oaks, maples, and chestnuts, which have many different kinds of long-vesseled wood cells, complicated fibers, and companion cells. The many woody body cells present in the wood of such conifers as the spruces and firs make them excellent sources of wood pulp for the manufacture of paper. Such so-called hardwoods like the poplars, which also have many woody body cells, are softer than some of the conifers and are also used in the paper industry. The uniform structure of their wood makes the conifers excellent timber trees, producing an even-grained, easily split and worked wood that is widely used for many purposes.

In the conifers, the male fertile leaves (stamens) and the female

fertile leaves (carpels) are arranged on separate cones (Fig. 145). In most species both the male and female cones are grown on the same individuals, but on different branches. The junipers and yews form their cones on separate male and female plants. The fruiting structures are formed on small lateral twigs of the new spring growth, while the main terminal growing point produces only new vegetative growth as long as the tree is alive. There are many kinds, shapes, colors, and sizes of cones. A few arise individually, others in clusters. The male structures are usually much smaller than the female. Those of the sequoias are only an inch in height, and the female cones of some pines are over

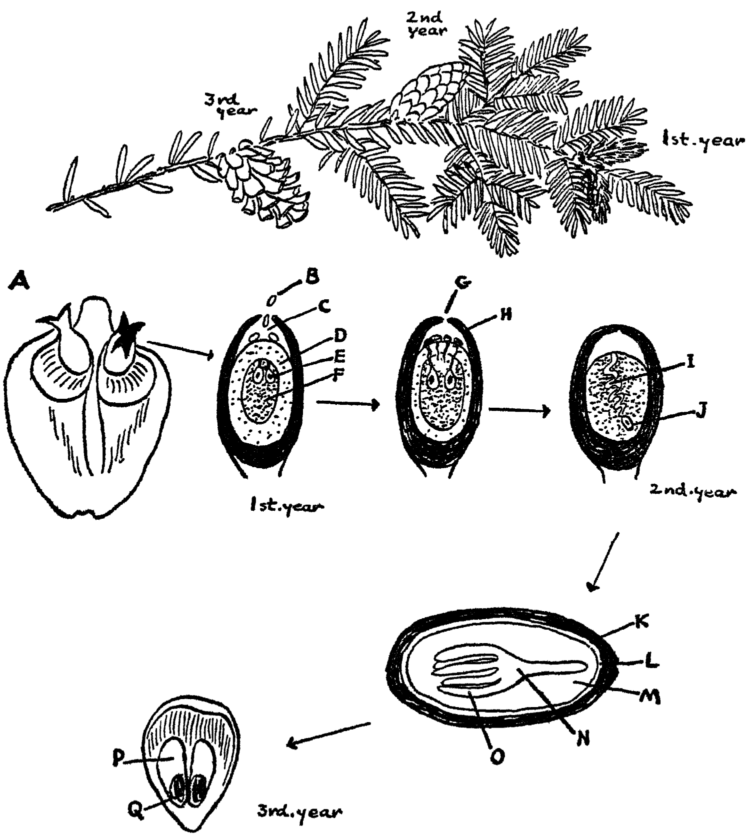

Fig. 154. Reproduction of pine: (a) female ovules, (b) pollen grains, (c) pollen chamber, (d) nucellus, (e) female gametes, (f) embryo sac, (g) micropyle opening, (h) integuments, (i) suspensor, (j) pro-embryo, (k) seed coat, (l) nucellus, (m) endosperm, (n) embryo or germ, (o) cotyledons, (p) wing, (q) seed

twenty inches in length. The pollen grains of the true pines and heron pines are supplied with two flaplike wings that aid their dispersal by winds. The ovules are usually upright, but in some species they are turned upside down, and the pollen tubes grow down the whole length of the nucellus tissue in the ovule to reach the female gametes. The pollen chamber is usually missing, but when present consists of a very small dry cavity. The embryo sacs of most conifers contain two female structures or archegonia, those of the sequoias have sixty, and certain cypresses have as many as a hundred archegonia in each ovule. But no matter how many female gametes may be fertilized in an ovule, it is a very rare occurrence when more than a single zygote ever develops into an embryo. Most conifer embryos have just two rudimentary leaves or cotyledons, but those of certain pines may have a dozen or more. The seeds of some conifers resemble fleshy, highly colored exposed berries; others produce their hard dry winged seeds in cones (Fig. 154).

There are about 570 species of conifers, which are grouped into 50 genera and 5 families, depending upon the structural make-up of their female cones and growth habits. These are the yew (Taxaceae), the pine (Pinaceae), the redwood (Taxodiaceae), the cypress (Cupressaceae), and the monkey puzzle tree (Araucariaceae) families.

Fig. 155. (a) Yew, (b) cedar

The yew family (Taxaceae) (Fig. 155) is sometimes considered to be a separate tribe of conifers because the female trees of this group bear cones that are reduced to a single carpel that supports just one or two exposed ovules. The mature fruit is a fleshy, usually red, berry surrounded by a loose covering tissue. There are eight genera divided into ninety species in this family, of which the yew (Taxus) and heron pine (Podocarpus) genera are the most important. The yews are slow-growing, highly branching evergreen trees with flat linear leaves that give a flat appearance to the wide-spreading twigs. Some species are often grown in gardens because of their many decorative red berries,

which ripen at Christmastime. Many yews have beautiful feathery light-colored leaves in the springtime that are very attractive. The wood is hard and takes a high polish, making it a valuable cabinet wood. Yews have been used for the manufacture of bows for hundreds of years because of their tough quality. The leaves, cones, and stems of these trees are very poisonous, but the berries are edible when ripe. There are forty species of heron pines (Podocarpus) distributed throughout the Southern Hemisphere, where they grow to be tall trees and produce large quantities of valuable lumber. Several species have been introduced into the United States, where they are grown for ornamental purposes.

The pine family (Pinaceae) (Fig. 156) is the largest and most important group of conifers, there being 31 genera divided into more than 300 species, of which 90 are common in the North Temperate Zone. The members of this family have needlelike leaves, and in most species the cones are woody when ripe. The seven best-known genera may be divided into two groups, depending upon the position of their foliage. Three genera, the larches (Larix), true cedars (Cedrus), and pines (Pinus), have leaves that arise in clusters from short stubs. The remaining four genera, consisting of the spruces (Picea), firs (Abies), Douglas fir or Douglas spruce (Pseudotsuga), and the hemlocks (Tsuga), have leaves that are distributed singly along the stems.

The larch trees (Larix) are deciduous conifers that are able to grow in cold lands under very rigorous conditions. They live farther north than any other conifers, being able to penetrate into Labrador. The tamarack or eastern larch grows in swamps. Many species yield excellent lumber, and the bark of some is used in the tanning industry. Although many kinds of conifers are called cedars, the members of the Cedrus genus only are botanically true cedars. They are numerous in several Mediterranean lands, where some species attain tremendous girths. The famous cedar of Lebanon trees live in groves on high mountainsides. Very few are left because entire forests were indiscriminately cut for their valuable wood. The deodar cedar is frequently grown as a garden tree in the southwest.

In the folklore of many people, various plants have been praised for their superior qualities and great value. These outstanding plants are called "kings," "queens," or "princes" in song, legend, and verse. The apple is considered to be the king of temperate fruits, and the date is called the prince of the desert. The rose, the myrtle, and frankincense are respectively known as the queens of flowers, perfumes, and spices. Indigo is the king of dye plants. Orchids are the aristocrats of the plant kingdom. In temperate lands wheat, in Asia and Oceania rice, and by the American Indian corn are considered to be the kings of cereals. The cotton plant is known as the king of fibers. The oak is praised as the

king of the forest, and the pines are rightfully called the kings of conifers.

There are over ninety natural species of pines known, and many hundreds of hybrid varieties have been artificially bred. The members of this, the Pinus genus, are among the most important commercial conifers and are widely distributed all over the world. They can be recognized from all other conifers by their long needlelike leaves, which

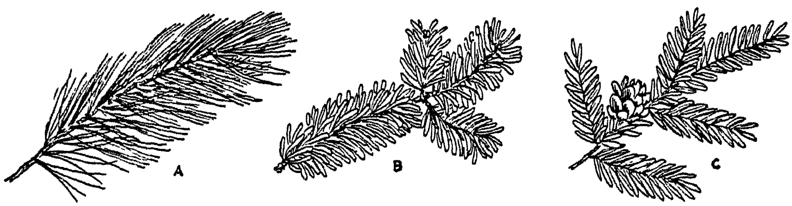

Fig. 156. (a) Pine, (b) spruce, (c) hemlock

arise in clusters from small spurs (Fig. 156). The other so-called "pine trees" belong to many other genera. Some pines are small and stunted, others tall and majestic in appearance. Many grow on poor soils in sandy plains and on rocky mountains where no other trees are able to make a stand. The two most ,important forest species are the yellow and white pines. The white pines (*P. strobus*) were once the magnificent monarchs of the primeval northeastern forests. The few remaining specimens are among the tallest eastern forest trees, sometimes attaining heights of two hundred feet. The wood is of such superior quality for interior structural and finishing purposes that only a few original white pines are left. This species and several other pines are among the most numerous forest trees that are being replanted in vacant lands. The longleaf pines yield large amounts of turpentine, and the stone pines are among the most popular ornamental shade trees.

The spruces (Picea) and the firs (Abies) are tall beautiful evergreen trees that have a very symmetrical pyramid form. They are widely used in Christmas decorations, and many species are especially cultivated for use as Christmas trees. There are about twenty species in each of these two genera, and their wood is an important source of pulp for paper. The red spruce yields a moderately soft but strong and elastic wood that is particularly excellent for sounding boards of musical instruments. The resinous substance that covers the outer bark of many spruces is called spruce gum and is used in the preparation of medicines. The beautiful form and color of the blue or silver spruce make it one of the most desirable conifers for ornamental purposes. The bark of the balsam firs is abundantly covered with balsam blisters, which yield

the Canada balsam of commerce. Its soft fragrant branches furnish the favorite "balsam pillows" for campers. The Douglas spruce or Douglas fir (Pseudotsuga) is a separate genus of very tall conifers that are the most valuable northwestern forest trees. They cover enormous areas of Oregon and Washington. The hemlocks (Tsuga) have the most feathery and delicate foliage of all conifers. Their wood is of poor quality, but the bark is a very valuable source of tannin.

Fig. 157. (a) Redwood, (b) juniper

Of the eight genera of evergreen conifers that are grouped within the redwood family (Taxodiaceae) (Fig. 157), two are native to the United States—the redwoods (Sequoia) and the bald cypresses (Taxodium). The remaining six genera are of Asiatic or Oceanic origin. The most valuable tree in the world is the true redwood, which grows to be from two hundred to three hundred feet in height. The biggest, tallest, and oldest living organism on earth is the "big tree," which may reach a height of 340 feet, a width of more than 30 feet at the base, and may be over 3,500 years in age, but its wood is of poor quality. The only other tree that approximates the height of the big tree is the Victoria eucalyptus (*E. regnans*) or gum tree, which grows in the province of Victoria in Australia to a height of over 300 feet. There are several extraordinary individual specimen trees that are wider than the big tree. Among these are the sacred baobab tree of India, which sometimes has a width of forty-five feet at the base. The inner wood of the famous chestnut tree of Etna is completely decayed and the outer bark and cambium are divided into several widely spread sections that cover an area of over a hundred feet in diameter. A certain plane tree near Constantinople has a hollow trunk that is over 165 feet in circumference, although only 100 feet high.

The bald cypress (Taxodium) is a tall deciduous conifer that renews its foliage annually and is one of the most valuable timber trees in America. These huge trees grow in the swamps of warm lands, being very numerous in the south Atlantic and Gulf states, and in the Everglades in Florida. The roots of these trees form a vertical outgrowth

that appears above the surface of the water. These "knees" have openings that permit the interchange of gases between the waterlogged roots and the atmosphere.

The cypress family consists of about 140 species of evergreen conifers grouped into 22 genera. The various kinds of shrubs and trees that are members of this large family have many diverse growing habits, but all agree in having small scalelike overlapping leaves that entirely cover the young shoots, and very small cones that in some cases develop into fleshy, berrylike fruits. The cypresses are widely distributed all over the world, and many species have been introduced into the United States for decorative landscape purposes. The members of the juniper genus have large fleshy fruits sometimes over two inches in diameter. Although the true juniper (*J. communis*) (Fig. 157) is a humble shrub, it has the distinction of being the most widely distributed tree of the Northern Hemisphere. In India the wood is burned as incense, and in Europe the sweetish fruit is used in the manufacture of gin. Several species of the juniper genus are commonly called cedars, the most common of which is the red cedar or savin tree (*J. virginiana*), which yields an aromatic wood that is widely used in the lining of clothes closets and chests. It is also used in the manufacture of pencils, and for poles, posts, and fences. The white cedar, which is a member of the Chamaecyparis genus, is a medium-sized tree that grows in swamps along the eastern coast from Maine to Florida. The wood of this tree is very durable, and is used in the manufacture of boats, pails, wooden utensils, shingles, posts, and poles. The canoe cedar (*Thuja plicata*), or giant arborvitae, which is Latin for "tree of life," was the most valuable tree to the northwestern Indians. These beautiful aromatic evergreens were so important in the civilization of those natives that they venerated the trees by carving images to form sacred totem poles on the living stems. The bark yielded tannins and colors; the fiber from the inner bark supplied material for cords, textiles, and blankets; the trunks were hollowed into boats; and the aromatic foliage was used in medicine and as floor coverings. The huts and barricades were built from the cut lumber and branches, and the roofs were covered with the twigs of these useful trees. The common arborvitae, or as it is sometimes erroneously called, the white cedar, has flattened leaves that give the plants a pressed appearance. This tree is often pruned and used as a hedge and ornamental specimen plant in many gardens. The fragrant light wood is highly valued in the construction of light boats and canoes, and it is one of the best woods for shingles. The slim forest-grown trunks of these trees contribute more telegraph poles and fence posts than any other northeastern conifers. The true cypresses are members of the genus Cupressus. These are all beautiful aromatic evergreen trees that are highly valued for their decorative slim pyramid forms (Fig. 24).

The monkey puzzle tree family (Araucariaceae). is composed of ten species of tall magnificent evergreen conifers that are natives of South America, Australia, and Oceania. They are characterized by their whorled branches and stiff small flattened leaves. The Chilean pine or monkey puzzle tree (*A. imbricata*) grows to a height of 150 feet and yields excellent lumber and turpentine. It has been introduced into California, Florida, and other warm lands, where it is widely grown as an ornamental street and garden tree. The bunya pine bears spherical cones that are sometimes more than a foot in diameter. Its seeds resemble plums and are the main source of food of many Southern Hemisphere natives. It has been estimated that ten trees produce sufficient seeds to feed one person. The most widely spread member of the Araucaria family is the Norfolk pine, which was one of the most popular and prized indoor pot plants in the United States and many European countries. Although in its natural state this tree grows to be two hundred feet in height and over ten feet in diameter, a system of artificially dwarfing young seedlings has been devised. This ingenious technique consists of planting seeds, removing the young growths, and rooting them in pots to make stock cuttings. When the stock cutting has from three to six tiers of stems, the young growths are removed and potted in turn. By the third generation the cuttings will grow into beautiful symmetrical small evergreen house plants.

Gnetales

Three very curious tropical and warm Temperate Zone genera known as Gnetum, Ephedra, and Welwitschia are grouped together in the highest order (Gnetales) of gymnosperms (Fig. 153). These curious long-lived desert plants are unique forms of vegetation that lack resin canals, have the internal woody structures of the true flowering angiosperms, and reproductive organs that are partly like those of the naked-seed plants and partly resemble true flowers. The Gnetales produce their exposed ovules and seeds on special, colored, cuplike supporting structures called perianths. Although no fossil remains of these plants have as yet been uncovered, it is believed that the Gnetales arose sometime during the Cretaceous period. Many botanists are of the opinion that the true flowering angiosperms evolved from some former type of vegetation that might have been a member of this or some similar order of plant life.

The Gnetum plants, which give the entire order its name, are woody vines or small trees with broad deciduous leaves that grow in the tropics. Their floral structures are arranged in cuplike supporting perianths that are arranged in whorls on special spikes. A typical female spike supports about three hundred ovules, and a male spike is made up of three thousand or more stamens. The fruit is a sweet, tasty red berry.

The Mormon tea (Ephedra) genus consists of thirty species of tropical and warm North Temperate Zone horsetail-like plants. These leafless shrubs have green joined stems that arise in whorls from widely separated nodes. The fruit is a delicious sugary red berry. The wood of two Asiatic species, *E. sinica* and *E. equisetina,* yield the valuable alkaloid drug ephedrine, which is extensively used in the treatment of colds and for other medicinal purposes.

The Tumboa plant or Welwitschia is restricted to the dry desert areas of southwest Africa. It consists of a long thick taproot and a huge tuberous stem that is sometimes over three feet in diameter and extends one or two feet above the ground. From the edge of the crown there extend two wide everlasting and ever growing leaves, which sometimes are split into many long straplike sections. The ends of these leaves are frayed and worn off by winds and sand, and new growth is constantly being added from the dividing cells in the stem. The top of the crown is depressed and wrinkled, each wrinkle marking the position of former floral structures. The reproductive structures are arranged in clusters on short stalks that arise from new crown growth. Although all members of the Gnetales order are visited by insects, it seems that a few species of Ephedra and the Welwitschia plants may be actually pollinated by insects, the pollen of the others being distributed by winds.

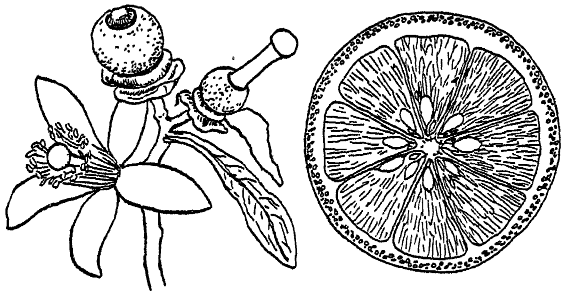

Fig. 158. Formation of citrus fruit

29. SEEDS AND FRUITS FROM FLOWERS

WE now come to the angiosperm division of the plant kingdom, in which are included all the flowering trees, shrubs, and herbs of our forests, fields, farms, and gardens. These are the highest and most modern forms of vegetation and embrace our main food, fiber, industrial, drug, flavoring, beverage, and ornamental plants.

The name angiosperm, which comes from the Greek and means seeds enclosed within envelopes, describes the outstanding reproductive characteristic of all flowering plants. Their ovules are formed and develop into seeds within special protective and covering structures called ovaries. Another distinguishing feature is that the cambium dividing cells of the stems and roots produce highly specialized, very complicated, and most efficient strengthening, supporting, and conductive tissues. The foliage of most flowering plants is composed of flat broad leaves that provide a large and efficient food-manufacturing surface.

As no transitional forms of vegetation between the naked-seed plants and the angiosperms have as yet been found, the beginnings and early evolution of the flowering plants are completely hidden in obscurity (Fig. 78). It is believed that this new type of vegetation may have arisen from several gymnosperm ancestors such as the Bennettitales and Gnetales, and evolved along many separate lines. A few leaves, stems, and floral parts of angiosperms have been uncovered from upper Jurassic and lower Cretaceous rock formations, and these are very similar to our present-day magnolia, buttercup, beefwood, mallow, butomus, water plantain, and barberry plants.

By the end of the Cretaceous period, about 60 million years ago,

some of the offspring of these primitive types had evolved into many different forms along several independent evolutionary lines. During the Tertiary period, which lasted about 59 million years, the angiosperms evolved in many directions and became modernized. They were so successful in their struggle for existence against the competition of the naked-seed plants, the revolutionary upheavals, and the great climatic changes of the Quaternary Ice Age that they became the dominating plants of the world, and are today found growing on the land surface of the earth wherever conditions are suitable. Some have invaded fresh waters, and a few species have adapted themselves for life in salty seas.

Before the establishment of the angiosperms on earth, man and his domestic grazing animals could not have existed. Our beasts of burden such as the horse, ox, camel, water buffalo, and elephant; our meat-, milk-, egg-, wool-, leather-, and fur-bearing animals such as cattle, fowl, sheep, hogs, goats, and rabbits; and our invaluable honey- and silk-producing insects derive all their food directly from the flowering plants. Man himself would have no grains, nuts, fruits, or vegetables to eat, neither would he have any hardwoods, rubber, cotton, linen, hemp, or the products of hundreds of other flowering plants that are vital to his everyday life.

The more than nine thousand known genera of angiosperms produce an innumerable variety of human foodstuffs. Those such as almond, apple, arrowroot, banana, bean, beet, breadfruit, cabbage, carrot, cassava, coconut, corn, date, melon, olive, onion, orange, peanut, potato, rice, spinach, sugar cane, taro, tomato, wheat, and yam plants yield the enormous quantities of sugars, starches, proteins, oils, minerals, and vitamins that feed the human race. Many flowering plants such as belladonna, castor oil, poppy, pyrethrum, quinine, and tobacco are important drug plants. We are all familiar with the beverages that are extracted from the roots, leaves, flowers, seeds, or fruits of birch, cacao, cola, coffee, grape, hop, lemon, and tea plants. The anise, caraway, camphor, cinnamon, ginger, lavender, licorice, laurel, mint, mustard, pepper, and vanilla plants give us some of our indispensable spices and flavors.

The 160,000 species of present-day living flowering plants show a remarkable variety in size, shape, and growth habit. They range in size from the microscopic duckweeds that are only one five-hundredth of an inch in diameter to the giant eucalpytus trees of Australia that reach heights of over three hundred feet and the baobab trees of India that have trunks over forty feet in width. Some, such as certain oak and olive trees, live to be well over six hundred years old, while certain desert herbs like the Abronia complete their life cycle from germination to maturity and seed production within a few weeks and then die. The cacti live in hot dry deserts while the water lilies have invaded fresh

waters. The saltbushes grow in salty seas and the cranberries thrive in acid bogs. Cotton plants are killed by slight frosts while edelweiss can endure the rigors of extremely cold winds and storms on high, frosty, snow-covered mountain peaks.

The insectivorous plants supplement their nitrogen requirements by devouring insects and other small animals, while members of the pea family harbor special nitrogen-fixing bacteria. Most flowering plants form tiny root hairs that are able to absorb the needed minerals from the soil solution without any aid, while some require the assistance of special fungus partners. Although grapevines have slender stems, their leaf surface is larger than that of the trees that support them. The Florida or Spanish moss lives as an independent attachment on trees, the mistletoe is a partial parasite, certain members of the fig family strangle their hosts, and the dodder and rafflesia plants have completely lost their ability to manufacture food and live as parasites on other plants. Many orchids and several other flowering plants are saprophytes that live on dead and decaying organic matter.

The most outstanding feature of a typical angiosperm plant is its flower. This is the highest and most efficient seed-producing organ that has been evolved by the plant kingdom. A flower is made up of several highly specialized leaves and short stems that have been especially modified and adapted for the production, support, and protection of the male gametes and ovules; for the distribution of the pollen grains of one flower, and their reception by the female structure of another flower of the same species; and for the development and dispersal of the completed seeds and fruit.

Flowers range in size from the microscopic blossoms of the tiny floating fresh-water wolffia plants, which can be seen only under a microscope, to the immense purple or brown rafflesia flowers. Many flowers are white, and the color range of others extends from the lightest pinks through the reds, yellows, greens, blues, and violets to the darkest purples and browns. But so far no true black flower has as yet been discovered growing wild, or has been artificially bred. Some flowers have no odor, many have a very pleasing fragrance, and a few such as skunk cabbage are vile smelling. The size and number of flowers that a plant may produce have no connection with the size or age of the plant that bears them. The blossoms of giant oak trees are very small, while those of certain orchids are larger than their stems. A small daisy plant may have a hundred or more tiny blossoms in each one of its many flower heads, while certain kinds of oak trees bear a few flowers only.

Hundreds of different kinds of flowering plants are cultivated and gathered all over the world because of their aesthetic beauty. They delight us by their pleasing shapes, colors, textures, and odors. They are also used in decorating our parks, gardens, and homes, and in the visual

arts. The flowers of certain plants are of great industrial importance. Beer is brewed from the flowers of hop plants. Camomile and linden flowers are used in brewing medicinal teas. The unopened floral buds of globe artichokes, cloves, and capers are tasty foods. Broccoli and cauliflower are well-known delicious vegetables. The petals of roses are used in making delectable jellies. Cassia, carnation, geranium, hyacinth, jasmin, jonquil, lavender, orange, rose, rosemary, tuberose, and violet are some of the most important fragrant flowers used in the confectionery, perfumery, and cosmetic industries. The thistlelike blooms of the safflower plant of India give us red dye for rouge and yellow to color many foods. The female organ of the saffron crocus flower is the source of the powerful yellow dye that is used universally for many purposes. Each saffron flower produces such a tiny amount of coloring matter that it takes about four thousand flowers to yield an ounce of dye.

Fig. 159. Inflorescence: (a) cyme of iris, (b) raceme of scilla, (c) spadix of arum, (d) umbel of carrot, (e) racemose cyme of chickweed, (f) corymb of flax, (g) ranunculus floral stalk in flower bud

30. INFLORESCENCE—I AM "BEGINNING TO BLOSSOM"

WE can divide all living organisms, plants as well as animals, into two groups depending upon their reproductive habits. Most insects and other small animals, as well as many spore-bearing plants and some of the highest types of flowering plants, produce just a single set of sperms, ovules, eggs, spores, or seeds during their entire lifetime, and then die. Practically all higher animals, all woody trees and shrubs, and many herbaceous plants are perennials, which bear a succession of offspring during a life span that may extend from several months to many hundreds of years.

Most perennial plants form only vegetative growth during their initial preparatory years. During this period of time they develop a strong supporting framework, accumulate a large store of reserve food, and mature into fruiting adults. Once they start to flower they continue to do so at regular intervals that alternate with periods of vegetative growth and

dormancy. A few tropical bamboos bloom only once every twenty years. Some, such as certain nut, olive, and apple trees, flower every second or third year. Most bloom regularly once a year. A few everblooming plants such as certain berries, roses, figs, and lemons experience several flowering periods every year.

Those biennial and perennial plants that bloom in the spring and summer form their buds during the previous season. The floral and shoot structures continue growth up to the time of frost or drought, remain dormant during the unsuitable season, and come into bloom when proper conditions for growth are present again. The floral structures of annuals and of those perennials that bloom late in the season continue growth without intermission from the time they are formed in the growing points until they are in full bloom.

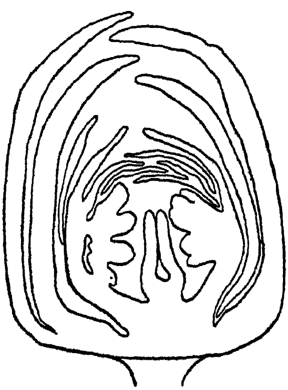

Fig. 160. An apricot flower bud

The formation of flowers is initiated in the growing points of the stems at certain definite seasonal periods characteristic of each species. At these times certain daughter cells are set apart to develop into reproductive organs. In such plants as peach and cherry the miniature floral structures are arranged within distinctive flower buds (Fig. 160). In others, such as apple and oak trees, the reproductive organs are placed together with the miniature stems and leaves to form mixed buds. In grape, pear, and tulip plants the flowers are borne at the ends of leafy twigs or at the tips of short specialized fruiting spurs. In breadfruit, cocoa, and wild fig trees the blossoms are placed around the stems, trunks, and larger branches. In linden trees the flowers arise from the large central veins of the leaves.

The arrangement of the flowers on a plant and the order of their appearance is called an inflorescence, which is a name that comes from a Latin word meaning beginning to blossom. In a few plants such as violet and pansy the flowers arise singly from a node. Generally the flower-bearing portion of a plant is quite distinctive from the vegetative part, and the inflorescence is formed on a more or less branched system called a floral cluster, in which the leaves are reduced to tiny scalelike bracts and the internodes usually remain very short.

Flowers are said to be solitary when the terminus of a stem ends with a single flower and none appear below, as in anemone, poppy, and tulip plants, or when each floral stalk that arises from a long-lived vegetative shoot ends with a single flower, as in apricot, peach, and quince trees. The arrangement of the flowers in clusters falls into several dis-

tinct groups that provide one of the means of distinguishing flowering plants (Fig. 159).

The most common form of branching and inflorescence, called indefinite or racemose, takes place when the terminal growing point of a stem or floral stalk continues to deposit new buds indefinitely as the older buds mature and bloom. The terminal growing points are active throughout the growing season, and the main stem of the plant and of each floral cluster is more vigorous and taller than the secondary branches or floral clusters. Branches or floral clusters arising from these are in turn progressively smaller. When the flowers in this type of inflorescence are placed one above another on a floral stalk, as in gladiolus plants, the older flowers will be near the base and the newer ones near the terminal growing point. When the flowers are side by side, as in carrot and dandelion plants, the younger flowers will be found near the center and the older ones around them. There are several kinds of indefinite floral clusters.

In some of the highest types of flowering plants many blossoms are grouped together on a common receptacle to form a tightly packed composite head (Fig. 163-H). Each tiny part of such a head is a complete and perfect flower called a disk flower. Every large, white, straplike petal that borders a daisy or sunflower head is a separate flower, known as a ray flower. The composite heads of dandelions and those of most double chrysanthemums and dahlias consist of ray flowers exclusively. Thistle and ironwood flower heads are composed only of disk flowers.

In some plants such as carnation, cherry, forget-me-not, orange, potato, persimmon, rose, and strawberry, the terminal growing point of a stem or floral stalk changes into a flower bud that blooms before any other blossoms appear either below or alongside of it to form a definite or cymose type of branching and inflorescence. In this kind of plant the terminal growing point of each floral cluster changes into a flower and further growth of the floral stalk is arrested (Fig. 159-E). One or more side branches may appear below the terminal bud or flower, and these in turn will grow more vigorously and become larger and taller than the primary stem, until those secondary growing points in turn change into terminal flowers or buds. Further branching may take place below each terminal flower to form a cymose inflorescence.

Chestnut, sunflower, apple, grape, viburnum, and some other plants have a mixed inflorescence in which both definite and indefinite types of branching and flowering occur in various combinations. In dead nettle each flower of a cluster is definite, as the center blossoms bloom first, but in the plant as a whole the arrangement is indefinite, as the lower clusters appear before the upper ones. On the other hand, in dai-

sies the blossoms in each flower head are indefinite, as the outer flowers bloom first, and the entire plant has a definite arrangement, because the terminal composite head is the first to appear.

When a bud that contains floral structures opens and the floral leaves expand, the flower is said to be in bloom. This blooming does not take place at all times of the year or day indifferently, but depends upon the inherited characteristics of the plant, which are controlled to a great degree by variations in the length and intensity of light, changes in temperature, the differences in atmospheric moisture conditions that the plant experiences, and various nutritional balances. Cape marigold blossoms close their petals when the air is moist. When the temperature falls the petals of crocus and tulip flowers fold up and protect the inner reproductive organs. Light controls both the formation of the flower buds and the movements of the flowers. The growing points of most angiosperms will not form floral structures when those plants are exposed to a continuous uninterrupted succession of light. Each kind of plant has its particular season of flowering. Almonds bloom in early spring, salvias during the summer, chrysanthemums in the fall, and poinsettias during the winter.

Just as there are floral calendars consisting of lists of plants that bloom at different months of the year, floral clocks have been devised in which plants are arranged according to the hour in which their flowers expand. Bindweed has a tendency to bloom about three A.M.; morning-glory and certain members of the potato family about six A.M.; purslane about noon; catchfly between five and six in the afternoon; evening primrose about seven; and many cacti at different hours of the night. Some plants, such as roses, gardenias, carnations, and orchids, remain in bloom many days in succession without ever closing. There are others, such as wheat blossoms, that bloom at a fixed time, remain open for a few minutes, then close permanently. Flax plants expand their flowers at five in the morning and are withered before midday. The star of Bethlehem opens its flowers several days in succession at eleven in the morning, and closes them at about three in the afternoon. Some night-flowering blossoms open several days in succession at seven in the evening, and close about six the next morning. The seed-forming true autumn flowers of violets never open. The violet blossoms that we enjoy in the spring are unable to produce seeds.

As a general rule, most wind-pollinated flowers open in the early morning hours. Flowers that are pollinated by those bees, birds, and animals that are active in the daytime are open during the warm middle part of the day. Flowers that are pollinated by moths, bats, and other night-flying animals are usually closed during the daytime and open at night.

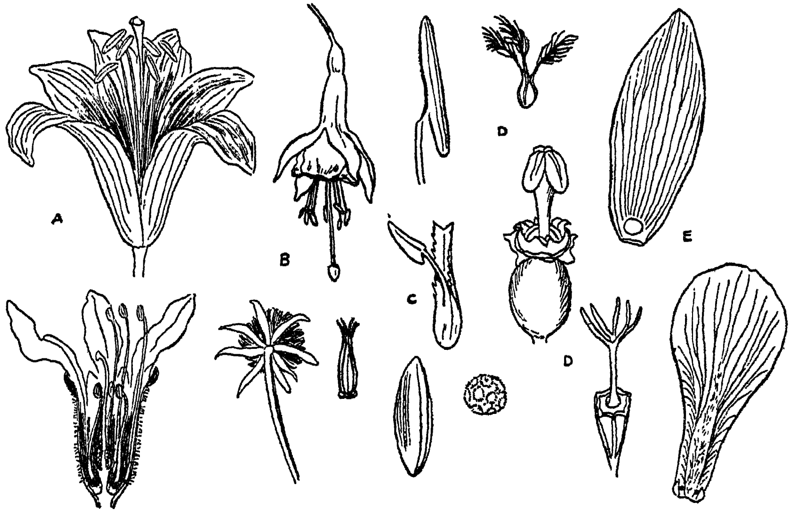

Fig. 161. Floral structures: (a) perianth, (b) calyx, (c) stamens and pollen grains, (d) pistils, (e) petals with nectaries

31. FLORAL STRUCTURES

A TYPICAL complete flower is not a single organ but consists of several series, rings, or whorls of various types of structures. Some are merely coverings and glands, while others are the essential spore- and seed-producing organs (Fig. 161). Beginning at the outside, we first find an outer layer called the calyx, which is usually hard, scalelike, and green. It may be united to form a cup, or separated into segments called sepals. Inside the calyx or outer whorl of protective leaves is the corolla, which may be separated into distinct petals. These are usually white or brightly colored and very prominent. The calyx and corolla together are known as the perianth.

The next whorl consists of one or more slender structures called stamens. These are the male spore- and pollen-producing parts of the flower. Next there may be present various types of bracts, hairs, glands, nectaries, and other protective and insect-attracting structures, which together form a disk. The innermost central portion is the female seed-producing pistil, in which the male gametes meet and fuse with the female ovules to form the zygote which develops into the young embryo plant of the next generation. All these essential inner reproductive

organs and the outer accessory protective and insect-attracting structures are inserted on a special supporting structure called the receptacle, which is at the tip of the floral twig. The floral parts are arranged and modified in countless ways. In some flowers one or more parts are missing, in others there may be a great number of a certain type of structure or organ, and a few of another kind. The receptacles of a heliotrope plant are small, and each contains but a single flower, while the receptacle of the fig plant may support several hundred individual blossoms.

In most flowers the perianth is distinctly divided into the outer thickened green calyx and the inner delicate-colored corolla. But in tulips, certain lilies, and other flowers the calyx and corolla are similar in shape, size, and color. The catkin blossoms of willow trees have no perianths at all and are called naked flowers. The perianths of many grasses, flowering hardwood trees, and other angiosperms that are pollinated by wind or water are often missing, and when present are usually small, green, and scalelike. In many flowers like anemones and fuchsia the corolla is missing and the calyx is highly colored.

The showy parts of some flowers are neither sepals nor petals, but still different structures called bracts. These are placed between the true foliage leaves of the plant and the tiny inconspicuous perianth of the flower. Sometimes they resemble leaves, as in anemones; often they lie close to the flower and resemble sepals, as in the hepaticas. A few bracts, as in bougainvillaea, dogwood, and poinsettia, are highly colored and resemble petals. The "lily" of the calla lily is a spathe that surrounds the tiny inconspicuous true flowers that are borne on the lower end of a long club-shaped stalk. Certain flower heads, such as thistle and chrysanthemum, are borne on or consist of large aggregations of highly colored or green bracts that in some cases are mixed with the true petals and sepals.

The calyx (Fig. 161-B) originates as a tough, usually green, scalelike covering that protects the tender floral parts when they are compressed within the bud. When the bud opens, the inner structures and outer scales enlarge and assume their various functions. The calyx of poppy flowers falls off when the bud opens. In ranunculus it is not detached until after the ovules have been fertilized. In citrus and apples it remains attached to the fruit. The calyx of ground cherry enlarges and becomes a thin yellow or red covering around the inner cherrylike fruit. In the lowest forms of flowering plants the calyx divides into several separate segments or sepals, while in the highest forms it remains entire and assumes the shape of a bell or tube that supports the petals. In roses and many other plants the sepals are covered with hairs. In nasturtium blossoms one of the sepals elongates into a long pointed tubelike nectar sac. In trillium blossoms the calyx is bright green, in peaches

a reddish green, in pomegranate a salmon or tomato red, and in larkspur it is blue, violet, or purple in color. The calyx of monkshood forms a white, yellow, or blue covering over the corolla.

The great charm and magnificent beauty of flowers are due mainly to the wonderful colors, extraordinary textures, and fantastic shapes that the corollas assume. The corolla differs from the calyx in usually being more delicate and highly colored. Its main functions are to protect the inner reproductive organs, attract pollinating insects, and act as a landing strip on which the insects alight in their search for nectar and pollen. The corollas of many insect-pollinated flowers have lines of contrasting color that radiate from the center to the edges of the petals. These lines direct the insects toward the nectar sacs and vital organs.

When the petals are all similar in size and shape, and form a corolla that can be divided into two equal halves, we say the flower is regular. The corollas of regular flowers may either be separated into individual petals or be more or less fused together to form various types of bell-shaped structures. The petals of such flowers as orchids and mints assume various unequal shapes and sizes, resulting in all kinds of irregular flowers. In some flowers such as certain carnations, roses, and peonies the number of petals is multiplied several times, and in addition many highly colored bracts may be mixed in together with the petals to form various types of so-called double flowers.

The male organs of a flower are called stamens (Fig.161-C). A typical stamen consists of four pollen-producing spore sacs attached to form a structure called an anther. The anther is attached to the tip of a slender threadlike supporting stalk or filament. In some flowers the filaments are missing and the anthers are attached to the petals or some other floral structures. In a few flowers the filaments are present but the anthers are missing.

The number of stamens present in flowers varies from one in cattail and willow plants to more than 3,400 in certain giant cactus blossoms, and is used as one of the means of distinguishing flowering plants. When ten or fewer stamens are present we say that the number is definite, when more than ten they are said to be indefinite in number. The stamens may be attached directly to the receptacle, to the female organ, or to some other floral structure such as the corolla or calyx (Fig. 162). They may be independent or more or less united into one or more bundles or whorls. They may be of the same height within the flower, or unequal in length. They are of various shapes, sizes, and colors, and may be thick, thin, straight, curved, smooth, or covered with hairs, bracts, or other structures.

In water lilies and some other primitive flowers we can readily see all the transitional forms of modified floral structures ranging from the sepals through the petals to typical stamens. As a petal is a modified

leaf, and a stamen in turn is a modified petal, the filament of a stamen corresponds to the petiole or stem of a leaf; the anther is a modified leaf blade; the connecting tissues between the spore sacs are the remains of a midrib; and the pollen-producing male spore mother cells are the daughter cells of the growing point that have retained their power of division instead of having been changed into body cells.

Between the male stamens and the female organs of many flowers there are usually present various types of structures that are collectively known as a disk. The disk may be composed of nectar glands and collecting chambers or nectaries, and all kinds of protecting bracts, burs, hairs, scales, and spurs may also be present.

Nectar is a sweet liquid that is formed as a waste by-product of various chemical reactions that take place in the cells of certain floral parts. It is very rich in sugars, waxes, oils, essential aromatic materials, and other substances. It is the only diet of some insects and small birds, and one of the main sources of food for many others. The amount of nectar produced may vary from hour to hour, from day to day, and from season to season, depending upon the kind of plant, various internal conditions, and climatic and other environmental factors. In some kinds of plants, such as buckwheat, the flow is in the morning hours only; in goldenrod it is at night; in many flowers the flow is continuous as long as the nectar is removed; in others the nectar may accumulate when a few or no visitors come to remove it. The melianthus flower produces an enormous amount of nectar, which drops over the sides, and the flowers "rain" nectar when shaken. Nearly all flowers have their nectar glands at or near the base of their petals or stamens. In some flowers the nectary is a small drop at the bottom of a petal, in others it is a small or large, open or closed cup, slipper, sac, spur, or tube. The nectar sac of the giant Madagascar orchid is a long pointed tube from one to two feet in length.

The pistil (Fig. 161-D) is the female spore-, seed-, and fruit-producing organ of all flowering plants. One or more are situated in the center of the flower, where they are protected by all the other floral parts. Just as the calyx is composed of sepals and the corolla is made up of petals, so the pistil consists of one or more specialized female fertile leaves or carpels that have been folded, rolled, blended, fused, and transformed into a single or several more or less attached flask-shaped structures. The lower enlarged portion of the pistil is called the ovary because it contains one or more ovules, each of which produces a female spore. The upper end of the pistil is a widened, glandlike, sticky, hairy, and irregular structure known as the stigma, which captures and retains pollen grains. In most pistils the stigma is carried at the end of an elongated pillar or style, in others the stigma is placed directly on the ovary.

The ovary may be superior, inferior, or half inferior, depending upon its height in relation to the other floral parts in the flower (Fig. 162). When the sepals, petals, and stamens are attached to the receptacle under the ovary, as in buttercup and tulip flowers, it is called a superior ovary. In honeysuckle, carrot, coffee, iris, orchid, and sunflower blossoms the ovary is sunken into the receptacle and the floral structures arise from the top of the inferior ovary. The ovary of some blossoms is said to be half inferior. In this case the receptacle is curved upward and assumes a cuplike shape. The ovary is placed at the bottom, and the other floral parts arise from the edges of the raised receptacle. A simple ovary consists of a single carpel. An ovary made up of two or more carpels is known as a compound ovary.

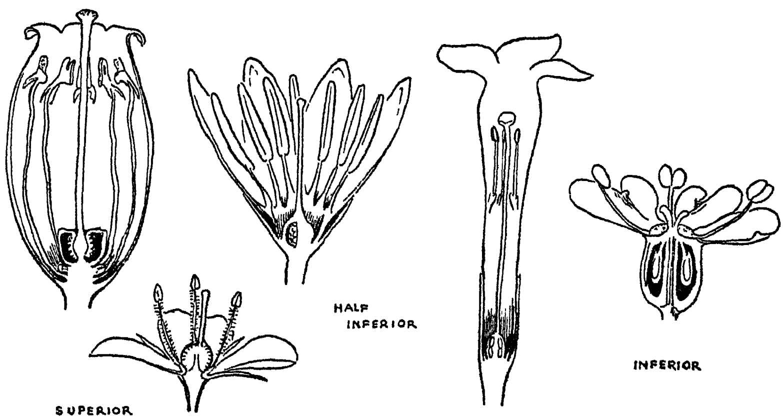

Fig. 162. Position of ovaries

Each division, cell, or chamber of an ovary contains one or more seed-producing ovules. These are attached by short stalks to a special point, line, or area known as the placenta. The placenta is made up of conductive tissues that convey food to the ovules, and it may be situated in the center or along the sides of the ovary. The number of ovules present and their arrangement within each chamber vary in different plants.

Each carpel has its own style, which may be smooth or hairy, short or long, erect or curved, thick or thin, even or grooved. The styles of a compound ovary may be either separate or more or less attached to form a thickened pillar. In some flowers the style of a single ovary may be divided into several strands. The style contains a central canal of conductive tissues that convey food from the placenta in the ovary to the stigma.

The stigma (Fig. 167-2) is the enlarged, flattened or branched, hairy or sticky, usually rough tissue that terminates the style. When the stigmas of several carpels are fused, the compound structure is usually grooved or branched, and the divisions mark the number of carpels that are united. When the pistils are ready to receive the pollen grains the stigmas of many insect-pollinated plants release a gummy, sticky substance to which the pollen grains adhere.

Fig. 163. Major groups of flowering plants (angiosperms): (a to k) Dicotyledons—(a and b) Apetales: (a) catkin, (b) acorn. (c and d) Diapetales: (c) rose flower, (d) rose apple. (e to i) Compositales: (e) single ray flower, (f) single disk flower, (g) receptacle, (h) composite flower, (i) achene fruit of marigold. (j and k) Gamopetales: (j) tobacco flower, (k) seed-producing capsule. (l) Monocots: bamboo

32. MAJOR GROUPS OF FLOWERING PLANTS

IN adapting themselves to the thousands of different kinds of habitat and other environmental conditions, the flowering plants have evolved in so many directions that today there are more than 160,000 known species, grouped into about 9,000 genera, 300 families, and over 30 orders. Some have remained in a primitive condition, but most have added, lost, or modified one or more of their vegetative structures and floral parts in so many different ways that their proper natural classification is an almost impossible task, and is continuously being revised as new plants are being discovered and more knowledge is gained. So many changes have taken place that today entirely different kinds of plants that have lived for many tens of thousands of years under the same environmental conditions may resemble each other in many ways, as do olive and laurel; or closely related kinds such as strawberry and apple, which have been separated and have lived under widely different conditions, hardly resemble each other.

Owing to the many differences that even closely related species may exhibit, certain characteristics are used as aids in classification.

It is generally agreed that plants having flowers that are made up of many separate parts, shallow nectaries, and superior ovaries are more primitive in character than those that have fewer, more complicated, fused floral parts, well-protected hidden nectaries, and inferior ovaries. But very few flowers either have model primitive characteristics or are highly evolved in all respects. Instead, most have one or more primitive traits and one or more highly advanced features. Many other complications make classification hazardous; many intermediate linking kinds are missing; many woody plants have highly evolved flowers, while some herbaceous kinds have very primitive flowers; and the members of many orders, and even of certain families that evolved from altogether different ancestors, have many vegetative and floral features in common. Therefore, a continuous series of compromises has to be made, and plant classifiers do not agree among themselves upon the value to be placed upon each different kind of flower and plant organization.

The procedure in grouping plants is to choose a certain outstanding genus as the representative kind. All other genera that have a great many similar characteristics are added to form a family. The name of the characteristic genus, which we will say is the rose (Rosa), is changed into a family name by adding "ceae," so that the family name of all the members of the rose family is Rosaceae. When one or more families exhibit certain outstandingly similar characteristics they are grouped into an order, and the name of the characteristic family of that order is changed into an order name by adding "ales." The Rosales order embraces the rose, saxifrage, witch hazel, Australian pitcher plant, and pea families. Unfortunately, botanists do not agree as to which families are to be included in a certain order. As the names of orders are based upon the kinds of families that are embraced, the names of the orders vary in different classification systems. For example, certain botanists classify the Euphorbia family as a distinct separate order. Other botanists may include it as just one of the families in the geranium, soapberry, or some other order.

All the flowering plants are grouped into two classes—the Dicotyledones and the Monocotyledones. The embryos of the dicotyledons have two rudimentary leaves, and their foliage leaves have netted veins. Their floral parts are usually grouped in series or multiples of four and five. Those that have woody stems and roots are provided with a continuous layer of cambium dividing cells, which add secondary tissues. Those dicotyledons that have herbaceous stems have their conductive tissues in characteristic patterns. The dicotyledons may be classified into four distinct groups, depending chiefly upon the organization of

their floral parts (Fig. 163). The Apetalae lack certain floral structures; the floral parts of Dipetalae are separate; the Gamopetalae have very complicated flowers that are made up of fused floral structures; and the Asterales bear many tiny highly evolved flowers tightly packed together on composite heads.

The thirty-five thousand species of plants grouped into the thirty families that make up the monocotyledon class of flowering plants are believed to have evolved from certain members of the buttercup suborder (Fig. 165). Their embryos are very small, never absorb the reserve food of the endosperm, and contain a single rudimentary leaf. Their foliage leaves are parallel-veined, and their flower parts are in series or multiples of three. With the exception of the bamboos, palm, Joshua trees, and yuccas, they are all herbaceous in growth habit. As most have no inner layer of cambium dividing cells, they are usually unable to form any secondary tissues. Most of the increase in thickness or hardening of the stems is due to the enlargement, thickening, and hardening of the original cells that were laid down by the growing point. Their vascular bundles are scattered within the soft pithlike body cells without forming any distinctive patterns. The stems of many are hollow.

Dicots

The Apetalae (Figs. 163, 164) group of dicots consists of about twenty thousand species grouped into twenty families of plants whose flowers either completely lack a perianth or have petals and sepals that are indistinguishable. Some members of this group probably never had any petals or sepals and may be among the most primitive present-day living angiosperms. Others are considered to be highly evolved, because their floral structures are especially modified for efficient wind pollination. Many members bear their male flowers in elongated catkins, and others protect their vital male and female organs with hairs, bracts, and various other kinds of structures. Many of our most important hardwood forest and nut trees such as the beeches, oaks, willows, walnuts, elms, and sycamores, as well as the pepper vine, laurel, and buckwheat families, are members of this group. The goosefoot family is considered the highest evolved herbaceous Apetala, and the euphorbia and chestnut families are the most advanced woody families.

Many of our most important fruit, vegetable, and ornamental plants are members of the Dipetalae group, which embraces about fifty thousand species grouped into a hundred families. The flowers of most of these plants are made up of many separate petals, sepals, and stamens, and the carpels of the female pistil are rarely completely fused together. The floral parts are attached directly to a shallow receptacle, their many stamens are arranged in two separate whorls, and their nectaries

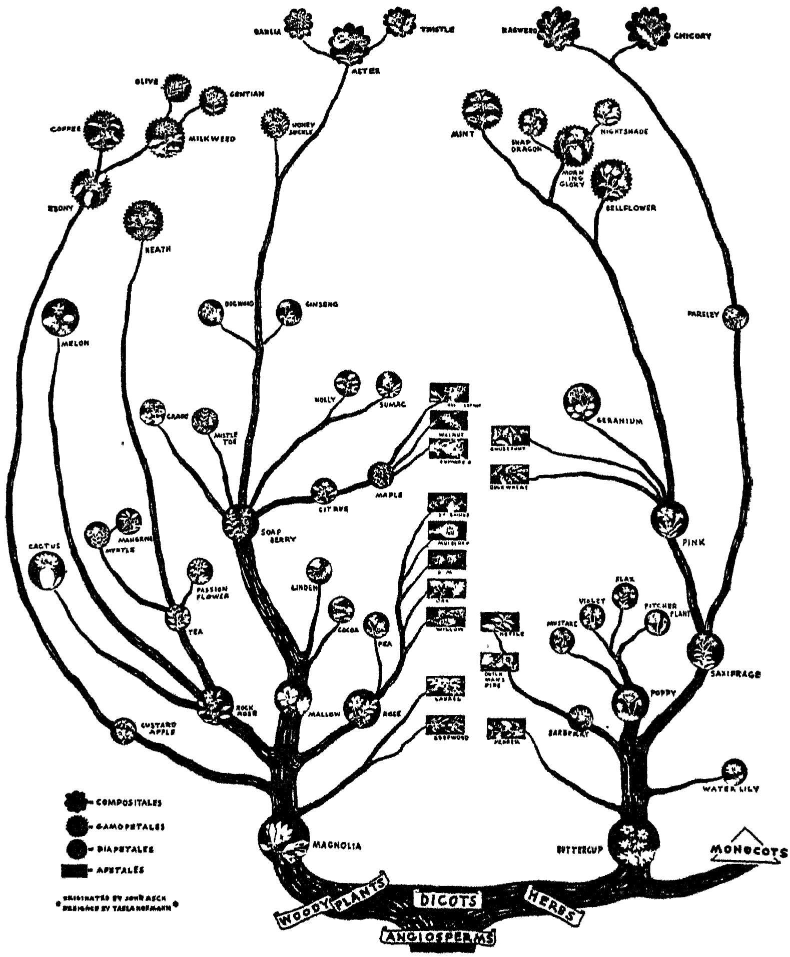

Fig. 164. Evolutionary chart of dicotyledonous plants

are freely exposed. The magnolia suborder embraces the most primitive woody plants, many of which are considered to be among the ancestors of most of the predominantly woody families, and the buttercup suborder includes the ancestors of most of the herbaceous flowering plants. Some of the most important woody families are the mallow, rose, melon, cactus, rue, myrtle, grape, holly, and mangrove. Among the most common herbaceous families we find the water lily, barberry, poppy, mustard, violet, saxifrage, pink, and geranium. The members of the Umbellales order, which includes the dogwood, ginseng, and parsley

families, have their highly evolved flowers arranged in very conspicuous umbrellalike clusters.

The Gamopetalae group embraces about thirty-five thousand species grouped into thirty-five families of plants whose corollas and sepals are fused together into various kinds of bell- and tube-shaped structures. Most families have few stamens that are arranged in one whorl around a compound pistil. They have very deep, well-hidden nectaries, and many manufacture various types of very valuable aromatic and medicinal substances. Some members of this group, such as potato, olive, blueberry, and sweet potato, are important food plants. Other important groups include the ebony, coffee, tobacco, milkweed, heath, honeysuckle, bellflower, and snapdragon families. The flowers of the members of the mint family are so efficiently organized that they are considered to be among the most highly evolved of all dicotyledons.

Between thirteen thousand and twenty thousand species, or over one tenth of all flowering plants, may be classified as members of the Compositae group. In these plants the tendency to arrange many tiny flowers tightly together on one head so that one insect may pollinate a great many stigmas during a single visit is developed to the ultimate. Those members that are pollinated by winds are likewise highly evolved, having very efficiently exposed anthers and stigmas. These plants not only have highly efficient pollinating devices, but also supply their seeds and detached fruits with various kinds of plumes, parachutes, hooks, burs, and many other ingenious dispersing structures. Their seeds and fruits are carried such great distances and they adapt themselves to so many different kinds of environmental conditions that they are the most widely distributed of all flowering plants.

They are generally grouped into three families. The largest and most primitive one is the thistle family, which embraces the globe artichokes, asters, goldenrods, daisies, sunflowers, zinnias, cosmos, dahlias, marigolds, and many weeds such as burdock, tarweed, beggar-ticks, and mayweed. The members of the ragweed family produce an abundance of tiny wind-blown pollen grains that contain certain substances causing hay fever in many people. The chicory family includes the dandelion, endive, salsify, and lettuce genera.

Monocots

The most primitive order of monocots embraces about five hundred species of aquatic plants, such as members of the water plantain, pondweed, cattail, and screw pine families. Many members of the screw pine family support their stems above water by exposed aerial roots.

The flowering rush order includes about fifteen hundred species, the most important of which are members of the arrowroot, pineapple, ginger, and banana families. The arrowroot family supplies us with

tapioca and various other forms of industrial and edible starch. The Spanish moss that lives as an attachment on many trees is a member of the pineapple family. The seventy species of plants in the banana family include our eating seedless bananas, seeded cooking bananas, the beautiful strelitzia or bird-of-paradise plant, Manila hemp, and the famous traveler's-tree, which stores in its stem large amounts of clear water that thirsty travelers can extract.

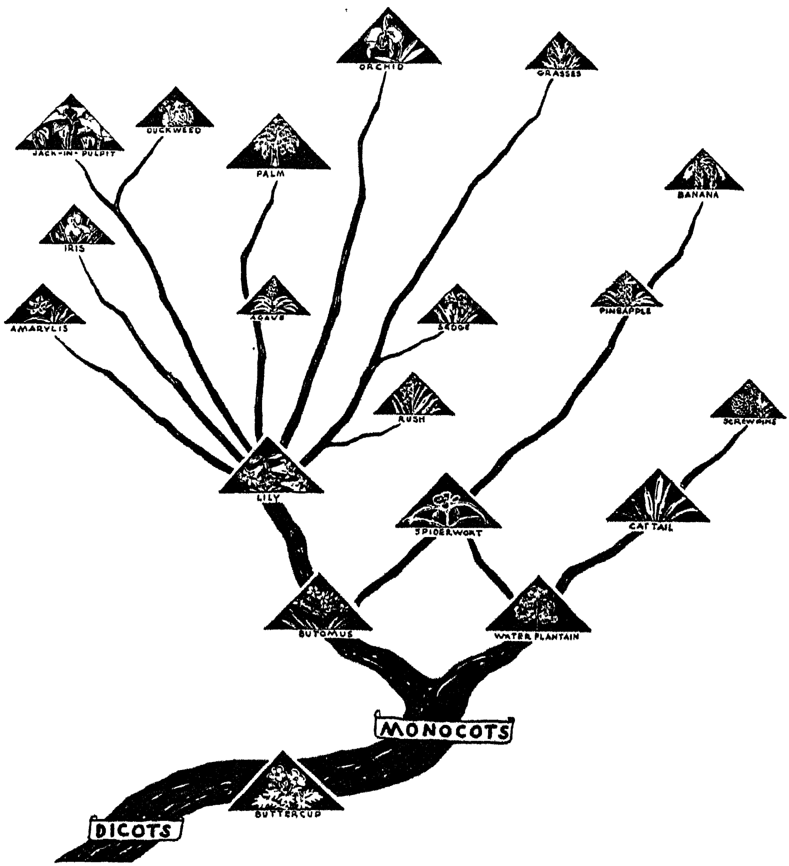

Fig. 165. Evolutionary chart of monocotyledonous plants

Among the most important members of the lily order, which embraces over five thousand species, are the lily, amaryllis, and iris families. Some members of the lily family include such important plants as onion, leek, yucca, asparagus, Joshua tree, tulip, hyacinth, and aloe. The amaryllis family embraces the century plant, sisal hemp, agave,

narcissus, jonquil, and daffodil plants. Among the fifteen hundred species of the iris family are the blue flag, gladiolus, and crocus plants. The palm family embraces fifteen hundred species such as the date, coconut, royal, palmetto, betel nut, sugar, oil, ivory, and various other kinds of palms. Among the fifteen hundred species of the arum order the smallest and largest flowers are to be found. The wolffia duckweed is the smallest flowering plant known, and the gigantic amorphophallus spathe is by far the largest flowering stalk. All these plants bear their flowers on fleshy spikes that are protected by large attractive sheaths. Many carrion flowers such as the skunk cabbage and a great many ornamental flowers like the calla lily and jack-in-the-pulpit are members of this large order.

The Glumiferae include 5,000 species of grasses, 3,500 species of sedges, and over 300 species of rushes. All these plants bear small inconspicuous flowers that are among the highest-evolved wind-pollinated organs. Just as all fish is plankton, so all meat is grass. The members of the grass family furnish us with our wheat, corn, rice, and sugar cane, which we process into bread, cereals, spaghetti, sugar, and other mainstays of our life. These plants also furnish our domestic animals with a large proportion of their food. Other important grasses are bamboo, barley, oats, rye, timothy, sorghum, millet, Kentucky bluegrass, orchard grass, and the buffalo grass of our prairies.

As we have seen, the dicotyledons have achieved the best arrangement for the pollination of most stigmas by a single insect in the Asterales group by arranging many tiny flowers together on one composite head. The monocotyledons reach their highest pollinating and seed-dispersing efficiency in the orchids. They produce very few pollen grains and ensure their use by various ingenious floral arrangements. Some resemble the insects of one sex in order to attract those of the opposite sex. The five thousand species in this group display a greater variety in form, color, texture, and arrangement of floral parts than the members of any other group, and they are so beautiful that they are known as the aristocrats of the vegetable kingdom.

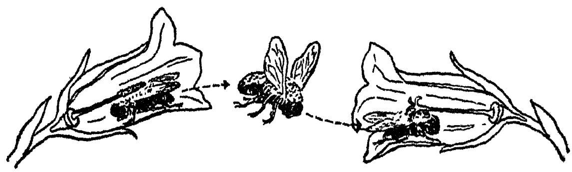

Fig. 166. Bee transferring pollen

33. POLLINATION

THE transfer of pollen grains from the male pollen sacs to the female stigma is known as pollination. The great variety in the number, size, form, color, texture, scent, and arrangement of the floral parts, and the difference in the season and the time of bloom exhibited by the flowers of the thousands of different kinds of angiosperms, are due to the countless ways in which the floral parts have evolved to effect pollination successfully.

Pollen grains are produced by a series of complicated events that occur in regular sequence. These processes start when a growing point leaves in a bud a generative cell that retains its dividing power. This cell divides itself innumerable times by typical cell division, forming several male spore sacs. The many thousands of cells that form the innermost layer of the sac are transformed into male spore mother cells. Each spore mother cell then divides itself first by a reduction division into two special cells, and these in turn immediately divide themselves once by typical cell division, thus forming four male spores, each of which develops into a pollen grain. Before a pollen grain is ready to be liberated its nucleus has divided itself into two cells, a large vegetative cell and a small generative male gamete-producing cell, which are the only representatives of the male gametophyte generation of all flowering plants. The vegetative cell represents the male gametophyte vegetative growth, and the generative cell is the only remaining vestige of a male gamete-producing organ. In most plants the pollen grains are already formed in the buds, and the spore sacs are ready to liberate the mature pollen grains several days before the flowers open.

In a few plants such as rhododendron the four pollen grains of each spore mother cell remain attached to form a tetrad. In some species a tetrad splits in two and the grains remain attached in pairs, while in most plants they are separated into individual grains. The pollen grains vary in size from about 1/100th of an inch in iris to less than 1/3,000th of an inch in saxifrage. Under the microscope, grains of each species

show distinctive shapes, colors, hairs, and other characteristics. Wind-pollinated flowers produce many thousands of pollen grains for each ovule, most of which are wasted. These are usually small, dry like powder, and have flaps and other widened winglike adaptations to facilitate their dispersal by winds. On the other hand, flowers that are pollinated by animals produce only a few times as many grains as ovules. The male flowers of a wind-pollinated corn plant liberate over fifty million grains, while the insect-pollinated blossoms of certain orchids produce only eight pollen grains. The pollen grains that are carried by animals are usually relatively large, sticky, and covered with hooks, burs, and other structures that enable them to stick to some part of an animal.

The length of life of pollen grains varies greatly. Generally pollen grains that are formed early and those that become wet remain alive for short periods only, while those that are formed later and those that remain dry live longer. The pollen grains of most grasses remain alive for one or two days only; pansy and cherry pollen is viable for about three weeks; carnation, grape, nasturtium, and peony pollen is good for about two months; tomato pollen can germinate after a rest period of from three to five months; corn and tobacco pollen remains alive for several years; and date pollen may be used as much as ten years after being shed if properly stored.

Direct or self-pollination occurs when the pollen grains of an anther contact the stigma of the same flower. This can take place only when the anthers are above and close to the stigma. In some plants self-pollination takes place even before the floral parts expand and the flower is in bloom. In certain milkweeds and in a few other plants the pollen germinates, and the pollen tube grows into the stigma before the pollen grains are shed. In the seed-producing flowers of violets the entire corolla remains closed, and in pea, bean, and snapdragon flowers the petals that protect the vital organs are fused so that no foreign pollen can come in contact with the stigma unless brought in by a heavy insect, such as a bee, which is able to separate the flap from the rest of the corolla and enter. Wheat blossoms remain open for only fifteen minutes. If pollen from another wheat blossom has not reached the stigma in that short period, the protecting floral leaves, bracts, and hairs fold together again and self-pollination takes place.

The vital organs and accessory floral parts of the blossoms of most flowering plants are so arranged that self-pollination is impossible. In such plants the pollen from another flower must be brought by some outside agency to effect indirect or cross-pollination. A few plants assure cross-pollination by forming unisexual or imperfect flowers that have either stamens or pistils only. In some plants, such as asparagus, chestnut, date, hop, and willow, the two sexes are on separate male and female individuals. In others, such as corn, buckwheat, cattails, many

nut trees, oak, and wild rice, the two kinds of flowers are on the same plants but arise from different buds. When both the male and female organs are present within the same blossom we say the flower is perfect. Some plants, like maple, grape, walnut, and certain members of the carrot family, have both perfect and imperfect flowers. In perfect flowers cross-pollination is assured when the anthers are below or too far away from the stigma; when the pollen grains are shed either before the stigma is receptive or after it has shriveled and died; or when the anthers are unable to release their pollen grains unless pressed by some insect that covers the stigma with its body and receives the grains on itself.

The most important pollen carriers are wind, water, and animals. All the naked-seed plants and about ten thousand species of flowering plants are pollinated by winds. Wind may carry buoyant pollen grains as high as three miles or more above the earth's surface, and as much as a hundred miles or more, in certain cases, away from the shedding parent plant. Among the most important wind-pollinated flowering plants are many of our common trees and shrubs, such as beech, elm, maple, walnut, willow, and wormwood; all the grasses, cereals, rushes, and sedges; such cultivated plants as date, hop, and evening primrose; and several obnoxious weeds such as dandelion, nettle, plantain, and rue. Some plants, such as buckwheat and rhubarb, are pollinated by both wind and insects. Many wind-pollinated flowers are visited by bees and various other insects that come in search of the nutritious pollen grains and nectar.

Most wind-pollinated forest trees bear their stamens in male catkins, and their female organs are borne singly in catkins or in various types of exposed clusters. Many bloom in early spring before the leaves appear, and have no nectar glands or scent. They produce enormous quantities of small, smooth, usually yellow, light powdery dry pollen grains that are covered with a waxy substance that protects them against moisture. The pollen grains of some wind-pollinated plants cause a very uncomfortable nose and throat irritation known as "hay fever" to people who are sensitive to certain kinds of pollen. Some of the most harmful "hay fever" plants are cedar, corn, elm, oak, oat, pigweed, poplar, ragweed, timothy, walnut, and wormwood.

Most flowering plants that grow in water produce their flowers above the surface and are pollinated by wind or insects. Some, however, use water as a pollinating agent. In certain pondweeds the female flowers are borne on the surface and the male flowers are submerged. The pollen grains are released from the anthers and float to the surface where they meet the stigma of the female flower. In salt-water eel or tape grass and in fresh-water waterweed plants the male and female flowers are formed underwater. When the female flowers are ready to be pollinated, they

rise to the surface and remain attached to the plant by long slender stalks. The male flowers are liberated just before the pollen grains are ripe. They rise to the surface just below the female flowers, and the pollen grains are released when the anthers come in contact with the hanging stigma. As soon as pollination is completed the stalk of the female flower coils up and draws the female organ underwater, where the seeds are developed in safety.

Many kinds of small animals visit flowers in order to obtain food, and while traveling from flower to flower in search of nectar and pollen they incidentally transfer pollen from the anthers of one flower to the stigma of another. These pollinating animals are so vital that if all the bees, beetles, butterflies, flies, honeysuckers, hummingbirds, moths, sunbirds, and wasps were to perish, practically all of our fruits and vegetables, many of our most important industrial plants, and almost all of our ornamental flowering plants would completely disappear from the earth after the death of the present generation, because there would be no seeds produced to replace them, and those that could be propagated by vegetative means would be unable to form any seeds or fruits. Most of the pollinating animals have evolved together with the flowers, and their mutual relationships involve some of the most remarkable phenomena in the whole realm of living beings.

Bugs and beetles with mouth parts that are less than one tenth of an inch in length crawl on small flowers that have shallow, fully exposed nectaries, and on blossoms that produce great quantities of pollen. Some of them actually do more harm than good because they eat and injure floral leaves and vital organs. Certain species of true flies that have short mouth parts occasionally visit small shallow flowers and incidentally partake of the nectar and effect pollination. A few species of flies, such as the drone and hover or syrphid flies, have feeding tongues one fifth to about one third of an inch in length and live exclusively on nectar, and are therefore good pollinators of many fruit trees and other flowering plants. The carrion flies pollinate vile, offensive-smelling flowers such as those of the carrion plant, rafflesia, skunk cabbage, and other aroid plants.

Some of the flowers that are pollinated by flies are known as prison or pitfall flowers, because they trap their insect visitors and do not release them until after pollination has been effected.

Wasps are indispensable pollinators of figs. A fig is an aggregation of hundreds of flowers that are developed along the inner lining of a hollow, pear-shaped receptacle that has a small opening at its free end. The best cultivated varieties, which are known as Smyrna figs, are borne on trees that produce female flowers only. The male flowers are borne by wild figs or caprifigs in which the wasps lay their eggs. After hatching, the female wasp leaves this fig laden with pollen and enters

a cultivated fig, where it wanders about trying to find a place to lay eggs. In the meantime, she pollinates the stigmas. As the many erect pistils form an uneven spiked surface, she is unable to lay any eggs and leaves. The fig ripens free of eggs or wasps. Those wasps that lay their eggs in the caprifigs perpetuate the race.

The hive bees and bumblebees have feeding tongues that are from about one fifth to half an inch in length, and they are among the most efficient of all pollinating insects. They are very desirable because they are industrious, work throughout the flowering season visiting many different kinds of flowers in regular succession, and gather both pollen and nectar. The bees are very intelligent and able to recognize flowers by scent, color, form, and texture. They are able to enter into various types of flowers that have intricate protective devices. They visit many flowers of the same species in rapid succession on each collecting trip, and often continue to visit that species exclusively throughout the day, or even during an entire blooming period. It is for this reason that it is possible to buy apple, basswood, buckwheat, clover, orange, and other kinds of pure honey.

Although most bees seem to prefer blue flowers, they also visit those of other colors. The flowers of many fruits and vegetables, and other plants are exclusively pollinated by bees. Bumblebees usually have slightly longer feeding tongues than hive bees and seem to prefer red flowers. They pollinate azalea, red clover, and snapdragon flowers. Although the young of butterflies and moths, when in the form of grubs and caterpillars, do a great deal of damage by feeding upon leaves and other plant parts, the mature adults of some species are very important pollinators. The mouth parts of the butterflies are somewhat longer than those of bumblebees, and they visit flowers whose nectaries are well hidden deep within elongated corollas. Many butterflies have a tendency to visit flowers that have their color. Many orchids, carnations, lilies, and honeysuckle bear typical butterfly flowers.

While most flowers that are pollinated by day insects are usually of bright hue and do not have a strong scent, those that are pollinated by night-flying insects, such as the hawk moths, are of white, yellow, or pale red color and have a pronounced fragrant odor. Evening primrose, petunia, and night-blooming tobacco are some hawk-moth blossoms. Some kinds of hawk moths have tongues that are as much as four inches in length, and a certain tropical species has a feeding tongue that reaches a foot in length and can gather nectar from Madagascar orchids.

Certain tiny night-flying moths pollinate desert candles or yucca plants.

Three kinds of birds are important pollinators: the hummingbirds, sundews, and honeysuckers. All these birds seem to prefer red flowers that have deep nectaries placed at the bottom of long tubular corollas.

They visit cardinal, trumpet honeysuckle, many orchid blossoms such as those of vanilla plants, and other tubular flowers. Some tropical night-flowering plants are pollinated by bats, and a few arums by snails.

Since the dawn of civilization man has known that date palms bear their male and female flowers on separate individuals. Ancient Assyrian and Egyptian earthen cylinders, tablets, stone carvings, and various other forms of inscriptions show how growers of those ancient days cut bunches of male flowers and attached them to female plants. Today plant breeders are able to apply the pollen of a great many different kinds of plants to desired stigmas by artificial means. The usual process is to cut out the anthers before the pollen grains are ripe, and to remove any other disturbing floral parts, bracts, and leaves. The pistil is then covered with a transparent, water-resisting cellophane bag that prevents the entry of any pollen or other foreign matter. When the stigma is ripe the desired pollen is applied with a special syringe that has a very small hollow needlelike outlet. The cellophane bag is pierced by the needle, and the pollen is dusted on the stigma. When the stigma is withered the bag is removed. In greenhouses and other places that lack pollinating insects, many fruits and vegetables are artificially pollinated by gathering pollen from the anthers and applying the grains to receptive stigmas with small camel's-hair brushes or by simply shaking the flowers when the anthers are shedding their pollen.

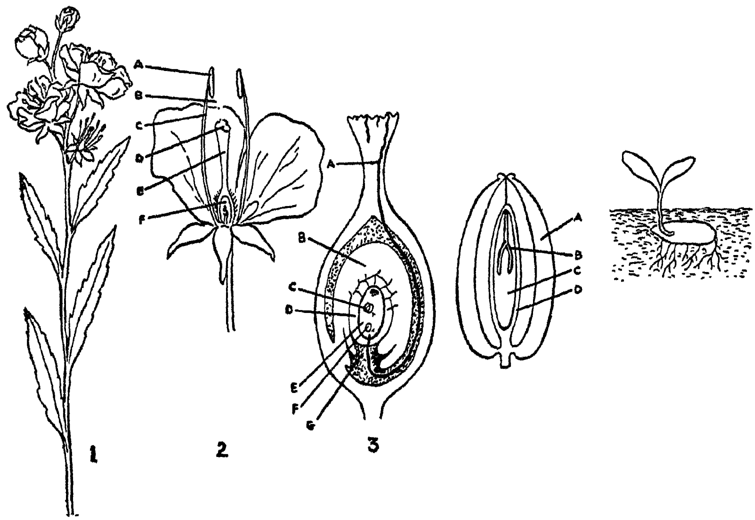

Fig. 167. 1. Flowering stalk in bloom. 2. Pollination: (a) anther, (b) pollen, (c) filament, (d) stigma, (e) style, (f) ovary. 3. Fertilization: (a) pollen tube, (b) ovule, (c) endosperm nuclei being fertilized, (d) nucellus, (e) embryo sac, (f) female gamete being fertilized, (g) micropyle opening. 4. Seed: (a) seed coat or testa, (b) embryo or germ, (c) endosperm or albumen, (d) nucellus. 5. Germination of seed

34. FERTILIZATION

AFTER a compatible pollen grain lodges on a receptive stigma it may, as in oak trees, remain dormant for several months, or it may start to germinate within a few minutes, as in most annual herbs. In germinating, the outer coat of the grain is ruptured and the inner coat is extended into a tube. The growth of the tube may be continuous until the ovule is reached, as in most flowering plants, or after a short initial growth it may stop growth temporarily and become dormant for several weeks or months while the ovule is being formed. In pecans the pollen tube remains dormant for four or five months before continuing its arrested growth.

In its downward growth the pollen tube is nourished by the stigma and style, and its direction may be outlined by guiding hairs, soft tissues, and other means. The time it takes for a tube to grow down differs in different plants and has no relation to the distance the tube has to travel to reach the ovule. In crocus flowers the distance varies from

three to six inches and fertilization is accomplished in one or two days. Although the distance is the same in saffron flowers, it takes the tube six months to reach the ovule. The growth of the pollen tube down the long style of a corn silk, which may reach a length of twelve inches, is accomplished in several days. While the tube is growing down the style the generative nucleus passes down the tube, and during its passage it divides once by typical cell division, resulting in two passive, nonswimming male gametes, which are released into the embryo sac of the ovule when the tube reaches the sac and is ruptured.

The ovules of most flowering plants are formed within the ovaries several days or weeks after the anthers have been formed and the pollen grains have been shed. Each ovule consists of a central female spore or embryo sac that is surrounded by a layer of nutritive tissue called the nucellus, and by one or more protective coats or integuments that do not quite meet at one end, but leave a small opening or micropyle for the entrance of the pollen tube (Fig. 167). The ovule may be upright, turned sideways, or completely turned upside down in the ovary. While the ovule is being formed, a certain cell elongates itself, separates from the rest of the nutritive tissue, and changes into a female spore mother cell. This female spore forms a large mass of cytoplasm that occupies the center of the ovule, and is known as the embryo sac. The nucleus of this large cell divides, its daughter nuclei divide, and these four in turn divide once by typical cell division, resulting in eight female nuclei, each of which still contains a single set of chromosomes. These eight nuclei and the cytoplasm in the embryo sac are the only representatives of the female gametophyte generation of all angiosperms. They are completed either just before the flower bud opens or sometime after the flower is in bloom. No female structure is formed; instead five of the nuclei eventually die. Two of the nuclei arrange themselves in the center of the sac and fuse together, forming an endosperm nucleus that has two sets of female chromosomes. The remaining nucleus enlarges and changes into an egg nucleus or female gamete. By the time that the end of the pollen tube enters the embryo sac through the opening of the micropyle, all these transformations have taken place, and the completed female gamete lies near the micropyle opening. When the pollen tube ruptures, one of the male gametes fuses with the endosperm nucleus that already has two sets of chromosomes, changing it into an endosperm nucleus that now has three sets. The other male gamete fuses with the female gamete, thus accomplishing fertilization.

The pollen grain and its tube form the bridge by which the male set of chromosomes and protoplasm are brought to the female egg nucleus. When the female nucleus or gamete, which contains the protoplasm and chromosomes of the female parent, is fertilized by the male sperm, the two sets of chromosomes and the two kinds of protoplasm are

united, and a new sporophyte generation is established. The fertilized egg cell, zygote, or oöspore that was formed by the union of the male and female gametes encloses itself within a wall and proceeds to divide itself many times, forming a short column of sporophyte cells in the embryo sac. One end of this column is fixed to the wall of the embryo sac, while the other end hangs free and is terminated by one or more large spherical cells. The column of supporting cells becomes the suspensor, which pushes the group of large cells that make up the proembryo deep into the embryo sac. The proembryo cells divide and redivide themselves innumerable times, forming a tiny miniature plant or embryo that consists of one or two rudimentary leaves or cotyledons, a growing point that will develop into the shoot system, a short supporting stalk, and another growing point at the other end that will eventually form the root system.

During the fertilization of the egg nucleus, the endosperm nucleus, which already has two sets of female chromosomes, receives a third set from the other male gamete. Angiosperms, therefore, unlike all other plants, experience double fertilization. This large endosperm nucleus divides and redivides itself innumerable times, and each one of the daughter endosperm nuclei reacts upon the cytoplasm in the embryo sac. The embryo sac increases in bulk at the expense of the nucellus, and other nourishing materials are brought to it by the placenta of the mother plant. Each endosperm nucleus surrounds itself with protoplasm and a cell wall, and the embryo sac is changed into many cellular compartments that are transformed into an endosperm or albumen tissue rich in many kinds of reserve foods for the use of the embryo when the seed germinates (Fig. 167-4). The nucellus is reduced to a thin film, and the covering walls or integuments are changed into various types of seed coats.

As the ovules are being changed into seeds within the ovary, the ovary wall or pericarp becomes thickened and develops into a protective, seed-distributing fruit. During the growth of the fruit the placenta and other food- and water-conveying tissues are gradually broken down and absorbed. In time the growth of the embryo and seed is arrested owing to lack of water and food, and the seed passes into a dormant state. At the time that the seed is mature, the size and position of the embryo in relation to the endosperm or albumen vary greatly in different plants. The embryos of certain orchids grow so slowly that their tiny seeds become dormant before the rudimentary leaf or cotyledon is fully formed. In this case the endosperm is very large and occupies practically the entire seed, while the embryo consists of a few cells only. The seeds of pepper, water lily, and ginger plants pass into a dormant state before the endosperm has absorbed all the food contained in the nucellus, and those kinds of seeds have a prominent nucellar or peri-

sperm food-containing tissue that has two sets of chromosomes, as well as an endosperm tissue that has three sets.

The embryos of a great many plants are fully formed but are very small in size at the time that they pass into a dormant state. Their nucellus is either reduced to a tiny film or completely disappears, and their endosperm or albumen is thick and rich with many different kinds of carbohydrates, fats, proteins, hormones, vitamins, various minerals, and other food and growth substances.

The embryos of almond, bean, peanut, sunflower, walnut, and some other seeds grow rapidly and absorb the endosperm before becoming dormant. Most of this digested food is converted into protein or fat and stored in the enormously enlarged rudimentary leaves or cotyledons of those embryos. Some embryos, such as those of cotton and melon plants, partially absorb the endosperm, and their seeds contain both albumen and enlarged embryos. The embryo sac may be completely filled with either the embryo, albumen, or both; may be partially filled with a liquid, as in coconuts, or may consist of an empty cavity.

As the ovule develops into a seed, the integuments increase in thickness, become hard and woody, and close over the micropyle, which may appear as a tiny opening or completely disappear. The scar of the seed is the point where the ovule was attached to the placenta. The inner integument is changed into a thin inner skin, and the outer integument is thickened and becomes the outer skin coat or testa. Those seeds remaining in the fruit when it is shed and not liberated until the fruit decays usually have relatively thin coats. The hard coverings of cherry, almond, and peach pits are not seed coats, but the hardened, thickened inner layer of the original ovary wall. The testa of the seeds that are liberated while the fruit is still attached to the parent plant becomes very thick, and receives various markings, sticky substances, flaps, plumes, burs, and other protective and dispersing devices. The fine hairs of cotton seeds are almost pure cellulose and are of such importance that cotton is not only the chief fiber plant but also the world's greatest industrial crop. Its qualities were appreciated by man long before written records were made. The nutmeg of commerce is the thickened outer wall of the seed. The seeds of some plants, such as nutmeg and passionflower, are provided with an additional covering called an aril. The aril may either completely cover a seed or consist of a branching structure. The aril of nutmeg seeds is the source of mace.

In some cases, especially when an ovary contains one, two, or several ovules, there may be as many seeds in a fruit as there were ovules. But when there are a great many ovules, rarely are all fertilized and developed into seeds, owing to various factors. The feeding capacity of the parent plant may not be sufficient properly to supply all the ovules with nutrients and water. Each ovule competes not only with every

other ovule in that ovary, but with every other ovule in the entire plant as well. Those ovules that are fertilized earliest have a head start, and those that receive a better set of chromosomes and protoplasm from the male sperms have a better chance than all the others. When small seeds are produced, the available amount of food may be distributed among many ovules, but when very large seeds are formed, they require a great deal of food, and fewer ovules will be able to develop into fertile, well-nourished, and properly protected seeds. Some plants produce seeds so small that they can hardly be seen with the unaided eye, while the seeds of coconut palms may be as much as a foot in diameter. The fruits of apricot, sunflower, and wheat plants contain a single seed; a pea pod has several; a watermelon may have well over a hundred; a poppy capsule may release several thousand, and each fruit of certain giant cacti and orchid plants may contain well over a million tiny, almost microscopic seeds.

In order to be fertilized, each ovule in an ovary must receive two male sperms that came from a pollen tube originating from a pollen grain. The stigma of a fruit that contains a hundred seeds was pollinated by at least a hundred virile compatible pollen grains, each of which developed its own tube and came in contact with its individual ovule. These one hundred pollen grains probably did not come from the same male parent; therefore, the endosperms, embryos, and seeds of those fruits, often the fruits themselves and the plants resulting from the growth of those seeds, may be quite unlike although all have the same female parent. When such a phenomenon takes place in the endosperm it is known as xenia. When the embryo has two unlike parents, it and all the growth it produces are known as hybrids. When pollination can be controlled, the color, size, texture, and composition of the embryo, endosperm, seed coats, fruits, and offspring may be regulated by the selection of pollen-producing parents that have the desired qualities.

Fig. 168. Huge oaks from little acorns grow.

35. FERTILITY—FRUITFULNESS—STERILITY

A NEW generation can be produced only when offspring in the form of miniature plants or embryos are developed. Each embryo must be provided with a rich store of food and protected by one or more coats in a seed. It is the function of flowers to produce such seeds. In order to do this a living pollen grain from the anther of a compatible plant must be transferred to a receptive stigma. The pollen grain must be able to germinate and form a pollen tube. The stigma, style, and ovary of the female organ must permit, and in most cases aid, the growth of the tube so that it is enabled to reach the embryo sac in the ovule at the right time.

The female gamete must be fully formed and receptive to the male gamete when it arrives so that both can unite and be transformed into a single fertilized egg cell or zygote. Finally the zygote must develop into a miniature plant of the next generation, the ovule must be changed into a seed, and the ovary must develop into a fruit that protects and helps disperse the seeds.

When all these events occur in regular sequence, and take place at the right time, the result is a fruit that contains living seeds having the power to germinate into new offspring. A plant that produces such living seeds in well-developed fruits is said to be fertile. When the ovaries of a plant develop into fruits that do not contain any seeds, or have seeds that are infertile, the plant is said to be fruitful. When a plant fails to produce both seeds and fruits it is sterile. Of course, a plant that pro-

duces only male flowers accomplishes its reproductive work by forming and liberating a large number of virile male spores enclosed within protective pollen grains. Many kinds of plants that produce seedless fruits, and those sterile plants that are grown for their tubers, roots, bulbs, stems, leaves, or unproductive showy flowers, and can be propagated by vegetative means, are highly prized and extensively cultivated by man.

At each one of the many steps from the beginning of the formation of the floral structures in the growing points to the production of mature fertile fruits, the male and female parts and any growth they produce, the zygote, the embryo, the seed, or the fruit, may be eliminated because of age, undesirable internal nutritive and water conditions in the plant, inclement weather, incompatibility between the male and female organs, wrong timing, and insufficient or too slow growth.

The first and most vital requirement that must be satisfied before a plant can produce fertile fruit is that its growing points must have the inherited ability to form daughter cells that are able to change into floral structures. A plant that is too young or lacks the inherited ability to produce such structures may receive the best of care and still be unable even to begin to form reproductive cells. A plant that has the inherited ability must be healthy, its heat and light requirements must be satisfied, and it must have a sufficient store of properly balanced reserve food and water so that its floral structures may develop into healthy male and female spore-producing flowers.

Many plants can be induced to form floral structures and bloom at desired times by various means, such as controlling the amount and duration of light; applying various chemicals in the form of gases, pastes, liquids, and radioactive elements; regulating the internal water and nutritive relationships by withholding water and applying nitrogen; pruning roots; driving rusty nails into a stem; notching or ringing a stem just below a flower bud so that a large percentage of descending food enters the bud instead of continuing its passage down to the roots.

After the male and female spores have been formed within the bud, the floral parts are expanded and the flower is said to be in bloom. Sometime during the period that the flower is in bloom the pollen is shed and the stigma is receptive. The stigma of a flower may or may not be receptive at the time that the pollen is being shed. If it is receptive, self-pollination may take place. If it is not receptive, some outside agent must bring in pollen from another flower of the same plant, or of another closely related plant, that sheds pollen at the same time that the stigma is receptive. In order that pollination may be successful, therefore, healthy, virile pollen must come in contact with a mature receptive, compatible stigma. Pollination cannot take place if the male and female spores and organs are retarded, injured, or killed by inclement

weather or destructive insects and diseases. Many early blooming flowers are killed by late spring frosts. Excessive heat, which is usually accompanied by intense light, dries out and may kill tender floral parts. A pollen grain that becomes wet may start to germinate and become spoiled before coming in contact with a stigma. A wet stigma may become unreceptive. Some flowers fold their petals when the humidity is high or when the temperature falls, and their vital organs become inaccessible to pollinating agents.

If pollinating agents are absent or unable to function, no transfer of pollen can take place, and if they are insufficient in number to visit all the flowers in an orchard or field, the crop will be smaller in direct proportion to the number of flowers that have not been visited. Many seed, vegetable, and fruit growers rent bees during the short blooming season to ensure proper pollination. Generally a hive containing about twenty-five thousand bees is needed to pollinate each acre of an orchard. Usually from ten to twenty hives are placed together near a road where they can be reached and tended with ease. Excessive wind, fog, heat or cold, and rain affect the flight of insects.

Pollination cannot take place if the pollinating flower is too far away or too close to the receiving flower, depending upon the carrying agent. A bee is seldom able to fly more than two miles from its hive during the best weather conditions; the flight of most insects is restricted to about a mile; and crawling insects are able to move very short distances only. The buoyant dry tiny pollen that is carried by winds generally does not fall straight down, but may be raised as much as three miles above the earth's surface, and alight many miles from its parent plant.

If more than one species is in bloom at the same time, there is competition between them for pollinating insects. The insects may be attracted by the color, scent, texture, nectar, or pollen of one species in preference to another. When buckwheat is in flower bees are attracted to the nectar in preference to that of another kind of flower nearer to the hive. The blossoms of pear trees seem to be among the flowers least attractive to insects, and some varieties are seldom visited when other kinds of flowers are in bloom.

The pollen grains of many plants may be germinated artificially when they are placed in various kinds of sweetened solutions and gels. By this means an unacceptable pollen grain may be transformed into an acceptable one, and a pollen grain that requires a long time to germinate or has a very slow-growing pollen tube may be gathered and treated as soon as it is formed. The germinated grain is then placed on another flower as soon as its stigma becomes receptive, thereby affording sufficient time for the pollen tube to reach the ovule when it is ready to receive the male gametes.

The stigmas of most flowers are freely exposed, and as they have no

selective ability they catch various types of tiny germs, spores, seeds, eggs, dust particles, and other forms of living and nonliving matter in addition to many different kinds of pollen grains. Of all the thousands of different kinds of substances that may be caught, only those living pollen grains that are receptive to the stigma of that particular kind of flower at that time are able to germinate. All the other living bodies die from want of a suitable environment, or are killed by various chemical substances that the stigmas of many flowers release. Although the stigma kills the unacceptable living bodies, it stimulates and nourishes the right kinds of pollen grains.

The reasons for nonbearing, from a fertilization standpoint, depend upon many known and some unknown factors. Some of the most important known factors are: the male and female organs, pollen grains, ovules, or gametes may not be fully grown, or may be injured, degenerated, or past their prime; hormones, vitamins, foods, and other necessary elements may be lacking; the pollen may arrive either before or after the female organ is receptive; the female organ and its parts may be incompatible to the male pollen grain and its growth; the stigma may be receptive and the pollen grain may germinate, but the pollen tube may not be able to grow fast or long enough to reach the ovule in time; and the pollen tube may reach the embryo sac but the gametes may be imperfect or unacceptable to each other.

When the entire female organ accepts a virile pollen grain, pollen tube, and sperm of its own flower, or of another flower of the same plant, or from the flower of a plant that is a member of the same clone, strain, or variety, we say it is self-fertile. If it does not accept such a pollen grain, or if the pollen grains of such a plant are not virile, it is said to be self-infertile, or self-barren.

When a female organ accepts the male parts from a member of another variety of the same species, it is known as interfertile. If it refuses to accept such a different kind of male growth, it is said to be interbarren. In extreme cases, under very unusual circumstances, and usually by artificial means only, a female organ can be induced to accept the pollen and sperm from a member of another species of the same genus. This can take place only when the chromosome make-up is similar and when the two species are very closely related.

There is no pollinating problem when a self-fertile flower is self-pollinated, because the pollen of that flower is virile and will contact its receptive stigma without the aid of any outside agent. The flowers of apricot, peach, walnut, and many other plants are self-fertile, but either their pollen is not shed at the same time that their stigmas are receptive, or their vital organs are so arranged that the pollen cannot come in contact with the stigma of the same flower. The flowers of such self-fertile cross-pollinated plants can receive the necessary virile pollen from an-

other flower of the same plant clone, strain, or variety only through the aid of some pollinating agent.

Many varieties of most of our common fruit trees, such as almond, apple, grape, orange, and many other kinds of plants, do not produce virile pollen, or for some other reason must receive the pollen from the flower of another variety of the same species in order to become fertile or fruitful. The pollinating problem of such self-barren, interfertile plants is very complicated, because a compatible type of pollen from the flowers of another variety must be brought to the desired flower by some outside agent. Plants that are specially grown to produce such virile, acceptable pollen grains are called pollinators. An ideal pollinator consists of a healthy plant that is not attacked by other kinds of insects and diseases, needs the same type of care at the same time, produces and releases a large amount of virile compatible pollen at the same time that the female organ of the receiving flower is receptive, and bears a good marketable crop.

Practically all seeds contain a single embryo that developed from the fertilized ovule. But a few kinds of plants, especially citrus, may have as many as a dozen embryos within a single seed. Such a phenomenon is called polyembryony. One of these is a normal embryo that developed from a fertilized gamete. The others are called apogamic embryos and are a result of the growth of one or more adjoining cells of the ovule. When a seed having many embryos germinates, it will produce one seedling that is a result of sexual fusion, and all the others will be vegetative growths from the parent plant. Sometimes the fertilized embryo in a seed having many embryos does not develop and all the seedlings will be apogamic in nature.

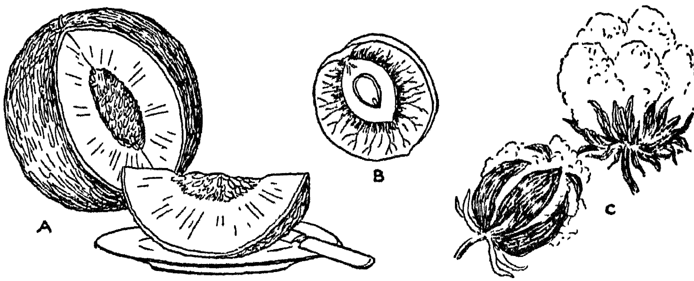

Fig. 169. Fruits: (a) melon, (b) peach, (c) cotton ball

36. WE ARE REWARDED

THE female organs of most flowers shrivel and die within a few days after being exposed unless their ovules are fertilized. These kinds of plants either bear fruits that contain fertile seeds, or do not produce any seeds and fruits at all. A few kinds of plants, such as banana, eggplant, grape, orange, and pineapple, are able to form seedless fruits or fruits that contain infertile seeds. Such a fruiting condition is known as parthenocarpy.

Most of these kinds of seedless fruits develop from ovaries that are stimulated into growth by certain vitamins, hormones, and various other activating substances released by a germinating pollen grain, a pollen tube that does not reach an ovule, or inactive gametes. Some may be activated by the pollen of another species, as in the Virginia creeper pollen on grape, by a dead pollen grain, or by a water extract containing the contents of certain pollen grains. In all these cases the stigma must be pollinated but the female gamete need not be fertilized.

The ovaries of a few kinds of plants are able to develop into fruits even when no pollen contacts their stigmas. In these very rare cases, either the female spore mother cell does not divide into two special cells, but forms an embryo by continuous typical cell division, as in many dandelion plants, or the ovary may be excited and activated into growth by a sudden electric shock during a lightning storm, an abrupt change in temperature or in water or nutritive relationships, the prick of a needle, the application of various chemical and radioactive substances, or by some little-understood internal or external physical or chemical stimulants.

As soon as the ovary is stimulated into growth it begins to enlarge

and its wall thickens and changes into a pericarp that is made up of one or more fleshy or dry, hard or soft, thin or thick layers. The ovary may enlarge slightly, as in dandelion, or increase enormously in size, as in watermelon. A single carpel gives rise to a simple fruit, and an ovary that is made up of two or more carpels develops into a compound fruit.

The appearance of the fruit depends upon the position of the ovary upon the receptacle. If the ovary is superior, a true fruit is formed. Such a fruit may be completely free of all other floral parts, as in apricot and peach; may have a calyx at its stem end, as in citrus and tomato; or the stigma may be changed into a parachute, some other type of carrying device, or may remain as a dried-up shrunken spot. When the ovary is either partially or completely embedded within the receptacle, an accessory fruit is formed. In accessory fruits the receptacle and sometimes other floral parts as well are enlarged, and incorporated into the growing ovary.

In apples, pears, and quinces a fleshy structure known as a pome is formed. The true fruit is the hard inner core that contains the seeds, and the fleshy part that we eat is the enlarged receptacle. In strawberries the true fruits are the hard tiny yellow or brown pits that lie on the surface of an enlarged, fleshy, highly colored, delicious receptacle. A fruit that develops from several simple ovaries of a single flower, as in blackberry and raspberry, is known as an aggregate fruit. When the ovaries of several flowers that grew on a single receptacle are fused into a single structure, as in breadfruit, fig, pineapple, and mulberry plants, a multiple fruit results.

Fruits may be fleshy or dry. The simplest type of fleshy fruit is a berry. In a true berry, such as cranberry, currant, date, grape, mistletoe, or tomato, the entire pericarp is soft, juicy, and covered by a thin skin.

A pepo is a berry that is completely covered by an enlarged receptacle (Fig. 169). In cucumber, pumpkin, and watermelon the rind is fused together with the fruit, and in banana the covering receptacle is a thin yellow skin that easily separates from the fruit.

When the inner portion of a berry is divided into several segments it is called a hesperidium. In this type of fruit each segment contains several seeds and the entire structure is covered by a thickened leathery skin that has many oil glands, as in lemon, orange, and grapefruit (Fig. 158).

Another type of fleshy fruit is a drupe or stone fruit (Fig. 169). The pericarp of these kinds of fruits is divided into three separate layers, the thin outer skin, an enlarged fleshy inner portion, and a very hard central pit that contains one or two seeds. The enlarged inner portion of coconut is dry and fibrous, in almonds and walnuts it is discarded, and the central hardened shell encloses one or two nutlike seeds. The enlarged fleshy portion of apricot, avocado, cherry, peach, plum, and

nectarine fruits is highly relished, and that part of an olive is the source of olive oil.

Some dry fruits remain closed and are shed when ripe. The outer skin is hardened, and often provided with various types of protective and distributing structures. Each tiny fruit of such plants as buttercup, dandelion, sunflower, and strawberry, contains a single small seed that is attached to a hardened pericarp by a stalk. Such fruits are called achenes. These very small fruits are usually provided with various kinds of dispersing devices such as hairs, hooks, and parachutes that develop from stigmas and sepals. In roses and several other kinds of plants the achenes are inside a hollow sphere. When the seed coat is tightly attached to a hardened pericarp, which may be smooth, as in corn, or hairy, as in wheat, the fruit is called a grain. A nut is a large meaty thin-coated seed that is enclosed within a very hard stonelike woody fruit. Some nuts, such as acorns and hazelnuts, are partially covered by various green husks; other nuts are enclosed within thickened completely overlapping husks that divide into three or more sections on ripening and release the true seed-bearing fruits. Each fruit of an ash, box elder, birch, elm, or maple tree consists of a thin winglike structure called a samara, which contains a single seed. In maple and box elder two fruits are attached and form a propellerlike structure.

Many kinds of dry fruits and a few fleshy ones remain attached to the parent plant, and open by innumerable ways to release their seeds when ripe. The seeds of these kinds of plants are provided with enlarged hardened coats and various kinds of distributing devices. The outer thickened rind of squirting cucumber becomes compressed and produces tension inside the fruit. Upon ripening, the tension becomes so great that the seeds are expelled with great force through a small opening. In larkspur, columbine, and peony the fruit consists of a single carpel, which splits open along one seam. The pods or legumes of all members of the pea family split open at both seams when ripe. The fruits of geranium, touch-me-not, and violet plants are made up of two or more thin valves or pods that either gradually open or suddenly spring apart and scatter their small, hard, smooth seeds. The enlarged thickened pods of such plants as clematis, cotton, cottonwood, and milkweed open slowly on ripening and expose their seeds, which are provided with plumes, parachutes, and other kinds of buoyant structures, to winds that carry the seeds away. The extremely small smooth seeds of such plants as lily, orchid, poppy, and tobacco are liberated from various types of capsules by means of many kinds of valves and other devices. The capsules of some of these plants are situated at the tips of long stems that are swayed by winds, and the seeds are scattered about somewhat like salt from a salt shaker.

We say that a fruit is set as soon as its ovary is activated into growth. During the time between fruit set and maturation, which may be a few weeks or many months, many changes take place. When dry fruits are formed, the body cells of the ovary thicken their walls, assume various shapes, and gradually lose water. The fruits that retain their seeds are shed, and those that remain attached to the plant split apart or separate their valves and release the completed dormant seeds.

Many different kinds of changes take place in those ovaries that develop into fleshy fruits. The body cells receive sap and other forms of elaborated foods both from the parent plant and from the green manufacturing cells that lie on the surface of the fruit. The amount of sap and other food substances received is so great that growth is rapid. While the seeds are being formed the immature fruits are unpalatable, owing to many different kinds of unpleasant, undigestible, and in some cases poisonous starches, acids, alkaloids, and tannins that may be present. As the seeds ripen, the contents of the body cells become soft and change into appetizing, aromatic, sweet, and very pleasing edible substances. Their outer walls are covered with a layer of protective wax. The green chlorophyll bodies gradually disappear and unmask the very attractive yellow, red, blue, purple, and in a few cases deep green pigments.

When the seeds are completed and in a dormant condition, and the fruit is ripe, certain cells in the node that support the fruit are activated, and they form an abscission layer that detaches the fruit stalk, permitting the fruit to fall. The cells of a fruit do not die immediately after it is shed. Instead, they gradually break down and permit the entry of various decomposing organisms. These fungus growths and bacteria decay the fruit and liberate the seeds.

A large percentage of the ovaries that are set never develop into fruits because of various unfavorable internal and external conditions. A very large well-paying crop is obtained when about 10 per cent of the flowers develop into marketable fruits from a tree that has a heavy bloom. The most harmful external factors are frost, dryness, strong winds, lack of sunshine, injury caused by animals, and parasitic forms of plant life. When sprays, dusts, gases, and other substances used to combat parasites contain harmful ingredients or are not applied at proper times, a great deal of damage is done.

Many ovaries are not set, or immature fruits are eliminated, because a plant is too young, is unhealthy, or cannot provide sufficient water and nutrients to the ovules and the fruits. It has been estimated that an average of about a hundred square inches of leaf surface, or about twenty to forty leaves, are necessary to manufacture sufficient food to mature properly a single fruit of an apple, peach, or orange tree.

In some cases, especially in some varieties of apples, peaches, and

pears when the set is very heavy, a certain percentage of young immature fruit may be removed, thus permitting the available food to be distributed to the best developed and located ovaries. Thinning should not be started until all the weak fruits have been shed by the plant, and has no effect on the remaining fruit when the ovaries have passed a certain state of development. When the small, weak, tightly packed, deformed, and diseased fruits are thinned out, the remainder are able to grow into large, presentable, highly colored, well-formed fruits that sell for higher prices.

When an extremely heavy crop of fruit is borne one year, the plant may become so weakened that it may be unable to form any floral structures, and may affect the crop of the following season. In some cases proper thinning assures a good crop every year. Thinning oranges and many other plants does not seem to have any effect on the crop of the current year or of subsequent seasons.

When a plant is supplied with too much water, the fruits may crack, or their contents may become mealy, unpleasant, of poor quality, soft, and susceptible to insect and disease invasion. If the plant suffers from lack of moisture it may weaken the fruits and force their premature fall by removing water from them.

The number of ovules that were fertilized and that are able to develop into seeds has an important bearing upon fruit set and maturity. Those fruits that contain many fertilized ovules develop many large conductive tissues in their supporting stalks, and those strengthened stems adhere strongly to the plant. Seedless fruits and those containing a small percentage of fertile seeds have a tendency to be easily shed by slight winds and other unfavorable conditions. Certain chemicals have been developed that inhibit the formation of an abscission layer. When such materials are applied, the premature shedding of the fruit or leaves is avoided.

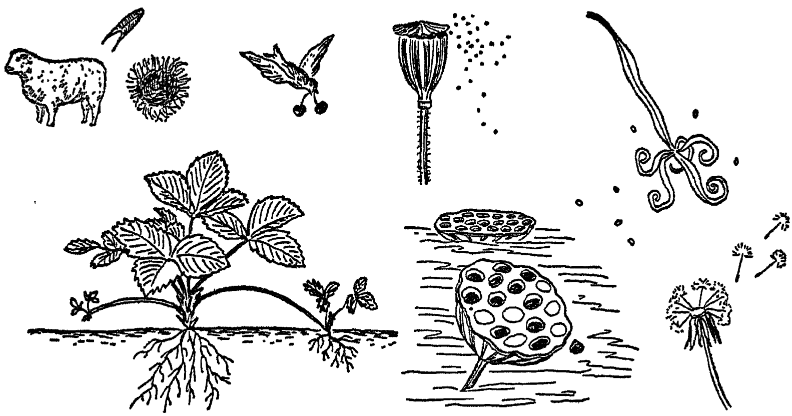

Fig. 170. Dispersion of seeds

37. MIGRATION OF PLANTS

EACH type of living organism is continuously striving to perpetuate its kind by reproducing itself and establishing its offspring in suitable habitats. Land plants reproduce themselves either by detaching certain portions of their bodies in the forms of fragments, spores, or buds that contain growing points and have the power of developing new individuals, or by producing seeds that contain miniature offspring of the next generation. Reproduction cannot take place unless a sufficient number of virile reproductive units are formed, separated from their parents, migrate to suitable locations, germinate, establish themselves as independent individuals, and grow into adults that reproduce themselves in turn.

As there is a limited amount of space, water, and food on the surface of the earth, and as these essentials are distributed among different kinds of habitats that are already occupied by various forms of life that liberate enormous quantities of reproductive units periodically, there is competition between different kinds of living organisms, between members of the same species, and between migrating reproductive units and the established vegetation. This competition leads to a life-or-death struggle for existence, and that species which is able to invade, occupy, and hold the largest area possible succeeds, while the others are completely suppressed and disappear off the face of the earth unless they are able to invade other suitable localities.

During the course of evolution, plants have developed various ingen-

ious devices that aid the dispersal or migration of their reproductive units. Some plants, like the mosses, ferns, certain algae, fungi, and grasses, and asparagus, banana, begonia, dahlia, potato, Solomon's-seal, and strawberry plants, have growing points in buds at various places in their stems, roots, or leaves. These buds are moved a few inches or several feet away by the parent plant, and in time the growing points establish dense colonies of separate individuals or attached plants (Fig. 170). The migration of such plants is very slow but is usually successful, since the new plants are nourished by their parents until they become fully established. Peanut, certain clovers, and other plants produce their seeds underground. The climbing butter-and-eggs or linaria plant places its seeds in the cracks of walls. These seeds grow into new individuals in the place where they were deposited and replace their parents, which die.

Most plants are unable personally to establish their offspring in suitable locations. Instead their reproductive bodies are detached and must migrate by other means. The flagellates, diatoms, certain other algae, fungi, and bacteria have the power of self-locomotion. These plants or their reproductive units are able to swim through water in search of food, a proper habitat, or a suitable environment. The seeds of certain grasses are covered with stiff hairs that move when moist. Such seeds can crawl short distances from their parents. The great majority of plants, however, are fixed in place, and their reproductive bodies cannot migrate by their own means or be established directly by their parents. The fragments, spores, buds, and seeds of such plants must be moved to other localities by some outside agent such as explosion of the fruit, gravity, wind, water, animals, or man.

The spore sacs of the ferns and certain fungus growths, and the fruits of such flowering plants as touch-me-not, euphorbia, squirting cucumber, lotus, and witch hazel expel their seeds with such force that they are violently hurled several feet or yards away from their parents (Fig. 170). The tiny achene fruits of the mints and many asterales bounce off a mortarlike calyx when the stems are bent by winds or passing animals. Certain seeds and many fruits are heavy, round, and smooth, and may be pulled downhill by the force of gravity. When originating on the sides of hills or mountains they can roll down considerable distances away from their parents.

In 1883 the vegetation of the island of Krakatoa was destroyed by a volcanic eruption. The nearest island that was not affected by the eruption is over twelve miles away, and the distance to the coast of Java is about twenty-five miles. After the disturbance the island was visited periodically by scientists and the vegetation was studied as it re-established itself. The first plants to appear were certain algae, fungi, ferns, and other plants producing tremendous quantities of tiny wind-swept

spores. Fifteen years after the eruption, fifty-three species of flowering plants were found. It was estimated that 60 per cent of these were brought by ocean currents, 32 per cent by wind, and 8 per cent by birds and other means.

The reproductive units of most aquatic plants and many land plants are able to float and remain undamaged in water or mud for several days, weeks, months, or years, depending upon the efficiency of their protective coverings and their floating ability. Some of these are carried great distances by ocean, sea, and lake currents, tides, streams, and the waters that run off the surface of the land after heavy rains. Coconut seeds are hollow and covered by fruits made up of tough, dry, buoyant fibers. They can remain afloat for long periods of time, but are damaged in a few days by the salts of the seas. Nevertheless, they are carried great distances very rapidly by ocean currents, and coconut plants have established themselves in many Pacific islands. Mangrove seedlings can remain afloat for at least two months and are carried by equatorial currents from West Africa to South America. Carex seeds are enclosed within large air-filled envelopes and can remain afloat for very long periods of time. The dry, winged, plumed, hairy, and light seeds of many weeds, cultivated plants, and forest trees are carried by streams and irrigation ditches, and sometimes form such thick growths that they clog waterways. Water-lily seeds and fruits remain afloat for several days, then sink into mud where they can germinate. The fruit of the American lotus plant resembles a small round boat that has many chambers, each of which contains and protects a seed (Fig. 170).

Just as many flowers depend upon wind for pollination, many plants use the same agency to disperse their seeds and fruits. In fact, all plants except those that grow entirely underwater or below the surface of the ground are subject to its influence. Although the scattering may not amount to more than a few feet, it is nevertheless of great importance as it transfers the seeds into fresh soil and beyond the influence of its parent, which might have an extensive root system or wide-spreading crown that would impair the germination of the seed or the growth of the seedling. The taller the plant, the greater will be the influence of the wind upon its seeds and fruits. As their seeds ripen, dandelion plants lengthen their flower stems and raise their fruiting structures to the actions of the winds.

Many fungi and bacteria produce such tremendous quantities of tiny buoyant wind-borne spores that they are carried everywhere and are continually present in the air. We cannot leave any food or other organic substance exposed without its becoming moldy. This means that the invisible spores that were floating in the air have settled down on a suitable medium and have started to grow. Likewise the seeds of many plants, such as poppies, chickweed, orchids, heath, and rush, are so

small and light that they are carried upward by air currents and dispersed great distances by winds.

The fruits and seeds of a great many plants are provided with various kinds of adaptations to aid their migration by winds. The fruits of many forest trees and the seeds of the conifers are winged; cotton, willow, and milkweed seeds are provided with many light hairs and fibers; the tiny achene fruits of dandelions have parachutes; those of clematis have plumed styles, and ground cherry seeds are enclosed within membranous envelopes that are filled with air. Russian thistle and tumbleweed plants break off at the ground when their seeds are ripe, and scatter their seeds as they are rolled and tumbled along the ground by winds.

Some of the most interesting adaptations for dispersal are found in seeds and fruits that are carried away from their parents by animals. There are two ways in which seeds are spread by animals. They may become attached for a time to some part of an animal's body, or they may be eaten and subsequently dropped unharmed. The grains of many grasses have beards or awns that adhere to the hairs of animals or the clothing of man. Sandbur fruits are provided with spines; the fruits and seeds of many plants such as cocklebur and bedstraw are covered with various types of hooks and barbs. Many nuts and other kinds of fruits and seeds are gathered by animals and buried for future use, and those that are forgotten are able to germinate. The seeds of gorse plants are gathered and planted by ants.

Many seeds such as those of mistletoe, sage, and ginger plants are covered with sticky substances and attach themselves to the beaks and feet of birds and other animals. Many wading animals pick up seeds that are lodged in the mud that sticks to their feet. When a bird or animal cleans itself sometime later after flying or walking to another place it drops the seeds. The seeds of many plants are contained within attractive, fleshy, colorful packages that are eaten by birds and other animals. The seeds, being protected by hard resistant coats, pass unharmed through the animal's digestive system, and are released undamaged far away from their origin. Birds are responsible for a large amount of seed dispersal because they are the principal eaters of fruits, fly great distances, and scatter seeds widely.

In his various industrial and commercial activities man is one of the greatest seed and fruit distributors. Seeds, fruits, spores, and vegetative propagating structures of a great many different kinds of plants are gathered and distributed intentionally all over the world. Many kinds of plants are dispersed unintentionally by man when their reproductive units become mixed with the seeds of cultivated plants, when they lodge themselves in screenings, hay, straw, manure, packing materials, foodstuffs, and many other substances. They are also transported great distances when they attach themselves to clothing, crates, bales, all

kinds of land vehicles such as wagons, automobiles, busses, trucks, and trains, and to boats, ships, and airplanes.

The direction in which plants migrate may be more or less influenced by the dispersing agent. Although most reproductive units are usually scattered in all directions, some may be carried in certain definite directions. A plant that sheds its wind-distributed seeds or fruits during the time of the year when that region is being swept by a prevailing north wind will invariably have its reproductive bodies blown northward. Even though there may be a suitable habitat a short distance to the south, that particular species may never be able to invade that territory. Migrating birds and other animals, ocean currents, streams, man's caravans, invading armies, shipping lanes, airplane flights, and other migrating agents that happen to pass plants when their reproductive bodies are being shed may likewise transport reproductive bodies in definite directions, and deposit them in certain localities.

In addition, the distribution of a species may be restricted by such barriers as extensive seas and arid areas, high mountains and other features that obstruct the migration of reproductive units.

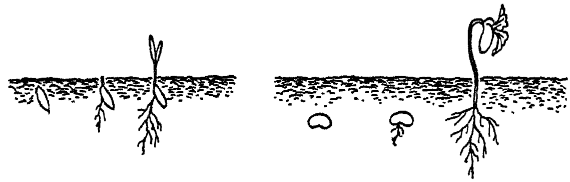

Fig. 171. Germination

38. A NEW PLANT IS BORN

WHEN a seed falls on favorable ground and receives a suitable amount of warmth, moisture, and oxygen, its embryo resumes its arrested growth and develops into an independent plant. The resumption of growth or germination takes place in several successive stages, which occur in regular sequence. Each stage must be completed before the following event is able to continue the process. It takes anywhere from three days to many months or several years from the time that a seed is sown until the seedling is above the ground, depending upon the kind of seed and the environmental conditions it encounters.

Germination begins when the seed coat is softened and is able to absorb water and oxygen, and continues as the water and oxygen are used to change the insoluble stored food into a soluble form. In this process the chemical messengers or hormones, the controlling genes, plastids, vitamins, the various mineral elements, and the digestive enzymes of the seed assume their various functions. The oxygen is united with the carbon of a part of the stored food and released as carbon dioxide gas. This respiration process releases the energy that held the various atoms together. The liberated energy, together with the water, is used to change the remaining food into soluble substances. The respiration or oxidation process sometimes takes place at such a rapid pace that a large part of the energy is liberated in the form of heat. When many seeds are stored in a large bin or grain elevator without being properly ventilated, the temperature may rise so high that a fire starts. Such an event is called spontaneous combustion.

As soon as the reserve foods are digested and converted into soluble substances they leave the cells in which they were stored and diffuse from one living cell to another until they reach the stem or root growing points of the embryo. When the converted food arrives at a growing point it is changed into living protoplasm and partitioned into cells. The transformation of nonliving food into living matter that takes place in the growing points of all plants, and in the bodies of all animals and

humans, is the most important event in the entire realm of nature, and a process that is a complete mystery to man.

As they are formed, the new cells are left at the ends of the rudimentary stem or root tips of the embryo, just below their respective growing points. They absorb a great deal of water, enlarge many hundreds of times, and increase the size of the embryo until it bursts through the softened seed coats or emerges through a special opening of the seed. When the embryo is free it grows rapidly by forming new stem and leaf cells from the reserve foods contained in the seed, and by enlarging the new cells. The root system usually leaves the seed first, grows downward into the soil, anchors the seedling firmly in place, and absorbs needed water, nitrogen, and other soil elements. The shoot system follows soon after, grows upward toward the light, and enlarges its leaves, which contain chlorophyll bodies that start to manufacture food. The new growing and expanding cells exert such pressure that they force the growing points through very closely packed soils, and in certain extreme cases they may even raise or crack clay formations, rocks, cement, and other hard substances.

When the leaf surface is sufficiently large to manufacture all the food, and the root system is able to supply the plant with all the water, nitrogen, and other elements it needs, the seedling becomes an independent self-sustaining plant. The most critical period in the life of a seedling is just after it has emerged from the ground and before it is well anchored and independent of the reserve store of food. During this critical time it is very weak and susceptible to dryness, cold, excessive heat, wind, and insect and disease attack. When a seedling successfully passes this critical period, its chances of survival and growth into a mature, reproducing adult are good unless its development is retarded by lack of space, light, water, and food due to the presence of the established vegetation, unfavorable environmental conditions, or parasitical organisms.

There are two general types of germination (Fig. 171). Either the tiny stem of the embryo elongates and pushes the rudimentary leaves upward, exposing them above the ground, or the growing point of the tiny stem forms new growth and leaves the cotyledons behind underground. The rudimentary leaves of such seeds as common bean, melon, and sunflower are brought up to the light, but soon after exposure shrivel up and fall off; those of most dicots such as castor bean, morning-glory, and maple enlarge, become green, and manufacture food after being exposed. The cotyledons of most monocots and of such dicots as pea, vetch, oak, horse chestnut, and walnut remain below the surface of the ground.

The successful germination of a seed and the growth of the embryo into a self-supporting adult depend upon many internal conditions and external factors. A seed that was formed by a weak parent may be de-

prived of its full complement of food, other needed substances, and protective coverings, and thereby be unable to feed and protect its embryo properly. The embryo may not be properly formed because of incompatibility between the genes of different parents or because one or more genes or entire chromosomes may be lacking or in excess. Furthermore, excessive rain, heat, cold, or other unfavorable environmental conditions that the parent experienced at the time that the seed was being formed are detrimental. In addition, various limiting factors that existed in the parent plant, such as poor conductive systems, lack of necessary elements, overabundance of water, or too rapid vegetative growth, may cause the formation of poor seeds. Although some seeds that become dormant before being fully formed may germinate, their seedlings are likely to be weak and unable to withstand unfavorable environmental conditions as well as seedlings that were fully formed and properly matured.

Except in bare areas that are covered with water or mud, successful germination usually occurs only when the seed is at its proper depth. There is an optimum depth for each kind of seed, which may vary with the habitat. Some seeds can germinate on the surface of the soil and plant themselves by contracting their roots, but most must be covered with soil by the action of water, wind, animals, rotting leaves, and other means. If a soil is covered with mosses, grasses, or dry leaves, the root is unable to penetrate into the soil and the seedling will die from lack of water and other soil nutrients. If it is planted too deep, the tiny embryonic stem may not be able to grow to the surface and expose the stem and leaves to light.

The embryos of such plants as mangroves continue growth without any interruption and are shed when they have developed into seedlings, while those of most plants are in a dormant condition when released from their parents. There are all gradations in the state of development of embryos, from those like the orchid, gingko, buttercup, and holly, which are undeveloped when dormancy sets in, to those that are fully developed and ready to germinate even before they are shed, as in pea, willow, and citrus seeds. The reserve food may be ready to be converted into soluble substances before dormancy sets in, as in orange seeds, or the stored food may have to undergo various changes while the seed is in a dormant condition, as in hawthorn seeds. The various types of internal changes that take place in seeds between the time that they are shed and the moment that they are ready to start to germinate are called "after ripening" processes.

The coverings of some spores, seeds, and fruits are so hard, thick, or tough that they do not permit the entrance of water, the exchange of gases, or the liberation of the growing embryo at the time that the seed is ready to germinate. The group includes those that are able to pass

through the digestive systems of animals unharmed, and those of most members of the pea family, mustard, cedar, rose, maple, peach, apple, ragweed, pigweed, cocklebur, and many water plants. The coverings of such reproductive units must be softened and made permeable by the actions of algae, bacteria, fungi, various soil solutions, air, light, heat, alternating freezing and thawing, water, or other agents.

Although all conditions for germination may be satisfied, the dormancy of certain seeds cannot be broken unless they are activated into growth by such stimulants as heat or cold, dryness or moisture, light or darkness, air or lack of air, radioactive substances, various acids, soil solutions, chemicals, or pressures. Most seeds require a certain amount of cold followed by warmth, or must experience several alternating cold and warm spells. Blue grass, mistletoe, tobacco, and celery seeds require light, onion seeds must be in darkness, while the seeds of most plants are indifferent to this factor. Many seeds such as those of willow, oak, hickory, sugar cane, and many water plants degenerate rapidly when exposed to air and must be buried deep in the earth or covered with water or mud soon after they are shed. The seeds of alfalfa, bean, citrus, and corn plants require a certain amount of heat, while those of conifers, basswood, cacao, rubber, tea, and elder trees must experience a certain amount of cold. River maple and certain rice seeds are killed when they become even slightly dry, and many other seeds rot in water.

All seeds gradually lose their vitality, the rate depending upon the inner organization of the seed, its coverings, and storage conditions. Seeds with resistant coverings are generally longer-lived than those that have thin or weak seed coats. All those conditions that aid in maturing and germinating a seed contribute to its growth or deterioration, while those conditions that prevent the softening of the seed coats, intake of water, exchange of gases, and growth preserve the seed. Those seeds that require light, warmth, air, and moisture for maturation and germination keep longest when they are deeply buried and tightly packed in a dry, cold, and dark substance.

But no matter how well a seed may be stored, it will eventually die because it seems that the chromosomes, hormones, and other vital growth substances of the protoplasm gradually disintegrate when in an inactive state. The seeds of willow deteriorate very rapidly and die unless they germinate within a few days after being shed. Those of most cultivated field and garden plants are able to live from one to two years only. Such seeds as lettuce, melon, and radish remain alive from four to six years. The properly matured hard-coated seeds of many weeds, grasses, legumes, mallows, mints, and celery, beet, and tobacco plants retain their viability for twenty or more years when properly stored. The seeds of certain pines are able to remain alive in their cones for as

much as forty years. Such cones release their seeds when they are activated by the heat of forest fires, when they experience extreme drought, or when they are stimulated by some other factor. The seeds of many water plants and of a few land plants may be conserved for as much as a hundred years or more when properly stored. Those of the Indian lotus (Nelumbo) plant are believed to be the longest-lived, as they have germinated two hundred years after being shed. Fantastic accounts of the germination and growth of seeds that have been found in Egyptian tombs and other archaeological uncoverings are the products of the imagination of certain unscrupulous persons.

All those seeds that have undeveloped embryos, unprepared food, or hard coverings, or require stimulation, must complete their development and be activated into growth after they land in favorable habitats before germination can begin or successfully terminate into self-supporting plants. These processes of maturation, softening of the seed coats, and stimulation may require weeks, months, and sometimes several years to accomplish.

As germination is postponed in many ways, and the vitality of the seed is retained over a long period of time, the seeds of a single parent or those produced in a single season by a certain species may go on germinating during a period of many years. This is a great advantage, especially to annuals that reproduce themselves only by seeds, as some of the germinating seeds may find conditions suitable for growth one year and not the following year or years. If all the seeds of a plant germinated at the same time, all might be lost because of cold, drought, or competition, or for other reasons.

Cultural operations often bury seeds, prepare them, deposit them at proper depths, and afford suitable environmental conditions, thus enabling the seeds to germinate many months or years after they have been deposited. This explains why there are persistent weeds in fields and gardens even though the areas are kept free from invasion for years. When land has been re-exposed after having been covered for a number of years by water, buildings, roads, or other structures, dormant long-lived seeds that were deposited before the ground was covered are able to germinate. The newly exposed ground will soon be covered with a rich vegetation that may be made up of several species of plants that grew from long-lived seeds, in addition to certain species that grew from newly deposited seeds that did not require any transformation.

Many reproductive units are deposited year after year in forests, woods, pastures, and other vegetable communities. When the lush vegetable coverings are burned over or cleared by some other means, the long-lived dormant seeds that were previously deposited and the new invading reproducing units are enabled to germinate and repopulate the land rapidly with various forms of vegetation.

Fig. 172. Destruction and rebirth

39. OUR CHANGING LANDSCAPE

THE surface of the earth and its waters provide a great variety of habitats in which different kinds of plants are able to establish themselves because they have evolved in certain definite directions. Each kind of living organism survives in that assemblage of environmental conditions which provide it with at least its minimum requirements of space, air, warmth, water, light, and chemical elements in the right proportions. A plant flourishes when its habitat furnishes it with the optimum quantity of all its requirements, and it is killed if the maximum of any one is exceeded, or if the minimum is absent. If we take, then, any area of natural vegetation, we must realize that the different kinds of plants that we find within it are not there by chance. They are there either because their ancestors originated in that locality or because they were able to migrate to that place.

Many kinds of organisms are continuously striving to establish themselves in every habitat, and only those that are in every way best suited for the particular conditions prevailing in any one spot will be able to maintain their hold. In every kind of situation, whether it be desert, mountain, plain, bog, forest, or prairie, the plants that grow naturally there have a long history of struggle and adaptation behind them, and each maintains its place by virtue of its special capacity to do so.

Plant Community

As there are many different kinds of regions that furnish the tens of thousands of different kinds of plants with a wide variety of habitats,

there are any number of ways in which plants group themselves to form various types of communities or associations. Those plants, such as many fungi, bacteria, grasses, and composites, that form many widely migrating reproductive units, and are able to live in a wide range of environmental conditions, may be present in a great many communities in many different parts of the world. On the other hand, those such as the welwitschia plants of southwest Africa, psilotum plants of Australia, and giant redwoods of California are found in small restricted localities because their reproductive units are not widely distributed, or because they require a very special set of habitat and environmental conditions. Each association may be made up of one organism, as in a pure stand of pines, or of a great many different kinds of plants, as in a mixed forest. The number and kinds present and the size of plant communities vary from place to place.

The various kinds of plant communities may be recognized and named on the basis of the most abundant or dominant species. Some of the most common forms of vegetation are those that lack chlorophyll; free-swimming or floating plankton; attached aquatic or benthonic plants; acid- or alkali-resistant plants; lithophytes or rock growths; sand-binding, desert, prairie, shrub, forest, and cultivated plants.

The plants that do not possess any chlorophyll and are therefore unable to manufacture their own food vary in size from microscopic bacteria to gigantic rafflesia plants. As most of these, excluding the seed plants, produce countless tiny buoyant spores, their reproductive units reach heights of several miles in the air and depths of many hundreds of feet in water and soil. They are everywhere, and form growths on every conceivable kind of living, dead, or decaying exposed underwater or underground organic substance. Some are very primitive single-celled forms of life; others, such as the dodder, are highly evolved flowering plants.

Plankton vegetation is composed of all the swimming and floating water plants, whether they are tiny microscopic green algae such as the flagalletes and diatoms, the enormous sargassum brown algae, water ferns, or the highly evolved duckweeds.

Those completely or partly submerged water plants that are fixed firmly in place by holdfasts or roots make up the benthonic vegetation of the oceans, seas, lakes, ponds, and streams. Some are primitive green, brown, or red algae, others are flowering reeds, arrowheads, rushes, water lilies, and rice plants.

The great majority of land plants are able to grow only in neutral, slightly alkaline, or slightly acid soils. In arid regions where there is scanty rainfall, as well as in marshes and near seashores, the salts are not leeched downward away from the root zone, but accumulate and raise the alkalinity to such an extent that all but a few resisting plants

such as mangroves, saltworts, and sea blites are unable to grow. In humid, poorly drained regions, many bacteria, fungi, and other decomposing organisms are unable to function because of the lack of oxygen. In those localities the neutralizing chemical reactions do not take place, as the calcium salts that neutralize the soil solution are not well developed. Such conditions lead to an acid reaction and are unable to support any but the acid-loving plants, such as blueberries, mountain laurels, azaleas, and cranberries.

Certain crustlike lichens, tiny mosses, and other primitive organisms are able to live on packed soils, rocks, and other hard surfaces because they release various enzymes and other elements that dissolve hard substances. These kinds of plants are able to absorb the slight amount of water and nitrogen they need directly from the atmosphere and their mineral elements from the rock material.

Certain plants such as cottonwood, marram grass, and squawbush are called sand binders because they have the ability to establish themselves on shifting sand dunes, steep mountainsides, and other unstable soils. Their extensive root systems bind the soil particles and hold them in place, and the stems of some elongate as the sand or earth piles around them.

Most of the earth's surface is composed of some kind of medium that is able to support plant life, and receives at least a minimum amount of heat, water, light, and air. A few localities are unable to support even the most resisting forms of plant or animal life and are barren. Most deserts, on the other hand, receive from five to fifteen inches of rainfall annually and are able to support a wide variety of plant life and some animals (Fig. 173).

Soil conditions, climates, and other factors determine the type of natural land vegetation that is able to grow and the kinds of agricultural crops that may be raised in each region. The most important soil factors are: past history; amount or depth; physical structure; water-holding capacity; quantity and quality of chemical elements and soil solutions; the number and kinds of living microorganisms, fungi, worms, and burrowing and other living organisms; and the amount and depth of dead and decaying organic matter that is present. The three most important climatic factors are warmth, water, and light. Temperature determines where native, invading, or cultivated plants can grow, and divides the world into great temperature zones north and south of the equator. Water is the most important element in determining the amount, size, and distribution of the plant life within each zone. The intensity of light and differences in the amount of day illumination profoundly affect plant behavior. Other factors such as elevation, exposure, intensity and direction of winds, nearness to bodies of water, and the presence or absence of pollinating, seed-distributing,

and otherwise beneficial animals, or of injurious plant or animal parasites, are of considerable importance. All these and many other factors are interrelated and act in unison on the plant organism, and determine whether a region is populated by prairie, shrub, or forest plants.

Fig. 173. American desert scene in springtime

Prairies are composed of annual and perennial grasses and other herbs that are able to live in regions receiving an average of about fifteen to twenty or more inches of rainfall annually. The annual species pass unfavorable drought or cold periods in seed form, and the perennial herbs have long-lived stems that are able to resist unfavorable climatic conditions by becoming dormant. They send forth new annual leaf- and flower-bearing stems during the favorable seasons. These types of plants are good soil binders and are able to withstand strong winds and other conditions that restrict the growth of shrubs and trees. When there is a scarcity of water or other necessary growth factors, the growth produced is very small, and bare patches of soil may appear. When there is an abundance of rain and the other conditions are also favorable, they may reach heights of six or more feet.

Lofty mountainsides, hills, plateaus, plains, and other regions that receive over twenty inches of rainfall annually but are otherwise unfavorable for the growth of trees are inhabited by various forms of chaparral, maquis, arctic, alpine, savanna, or other kinds of mixed shrubby and herbaceous types of vegetation. The distribution of the stunted trees, bushes, and shrubs that grow above the low mosses,

lichens, grass, and other herbaceous growths varies greatly in different regions, depending upon distance from the equator, elevation, exposure, depth of soil, winds, and other factors (Fig. 174).

Fig. 174. Alpine landscape

The limiting factors in soils that receive over thirty inches of rainfall annually are usually heat and light. In the north temperate regions that receive an abundant amount of water in the form of winter snows and summer rains, but experience low temperatures, the vegetation is restricted to evergreen coniferous forests or various formations of small shrubs and herbs. The many closely spaced leaves of the conifers are so arranged that they form a thick overhead canopy and shade the interior so well that it is impossible to see the sun in daylight or the moon at night. A typical conifer forest is clothed in perpetual shade and intense silence. The deep shade coupled with the layer of slowly decaying dry leaves does not permit the growth of any but the most resisting lichens and mosses to become established, and these are un-

able to live directly on the forest floor, but only as attachments on the trunks of trees.

On approaching the equator, the vegetation gradually changes (Fig. 175). Other forms of conifers, broad-leafed deciduous trees, mixed forests, and various types of more or less open woods and meadows dominate the landscape. The deciduous trees and their leaves are not so closely spaced as those of the conifers and permit a certain amount of light to filter down to the forest floor during the growing season. As they shed their leaves the ground is flooded with light during the late fall, winter, and early spring months. When the forest floor is bathed with light, various types of flowering herbs, bushes, and shrubs are able to form one or two layers of vegetation under the wide-spreading tops of the dominant tall trees.

Fig. 175. Settlement in tropical Africa

In certain hot tropical regions the rains are so frequent that the air is permanently saturated with moisture. In such localities the forest supports a wealth of vegetation that is arranged in a series of underground and aboveground layers (Frontispiece). The lofty trees support many kinds of strangling, climbing, scrambling, and leaning vines that

have unlimited growth and attain immeasurable lengths as they reach for the light. Many epiphytes grow as attachments from various levels of the trunks and branches of the dominating trees. Many kinds of green plants occupy the lower regions, and the dark forest floor is covered with a wide variety of fungus growths, flowering parasites, and saprophytes that thrive on other growing vegetation and on the thick layer of moist rotting organic material.

Plant Succession

Each association may be regarded as a living organism that experiences birth, growth, maturity, reproduction, and death. Associations originate when several plants of the same or different species invade a territory that affords a suitable environment. Existing habitats are destroyed or changed, and new habitats are established by various factors. Wind, frost, drought, rain, streams, fire, volcanic eruptions, glaciers, and man are some of the agents that may destroy established vegetation and form new habitats. Environmental conditions change vegetation, and vegetation in turn can change environmental conditions. Some of the changes that are effected by plants on their habitats are the formation of barriers against destructive winds, the filling up of ponds and bogs, the increased humidity of the surrounding air, the cooling of the atmosphere, the breaking down of rocks, the formation of new soils, and the enriching, binding, and drying of existing soils. By changing their environments, plants destroy the conditions that were suitable for their growth, and prepare a location so that it is acceptable to other forms of vegetation.

Because of the various changes that are continuously taking place, the composition of a plant community in a given locality differs from time to time. The variations may be rapid or so slow as to be imperceptible, but they finally lead to one or more species' being succeeded by others. The change may consist only of variations in the relative number of species already present in the community, or it may be due, in part, to the invasion of new species from other communities. The different species continue to supplement each other until some winning or climax form of vegetation is established that remains until it is killed by some outside agent. When a climax is destroyed, a new community becomes established.

This development of a community from birth to maturity is called plant succession. When underwater plants in ponds and bogs die, they are partly decomposed and form mats on which other kinds of vegetation can establish themselves. These in turn form soil, which destroys them and permits the successful establishment of herbs, which later give way to shrubs, and the succession may eventually be climaxed by

a forest (Fig. 79). Lichens are rock pioneers. They eventually die, and on decomposing their remains are mixed with rock fragments to form shallow soils. These are then occupied by mosses, which in turn form more soil. As soil accumulates there is a succession of growths until the climax is reached.

Part III: Plants and Man

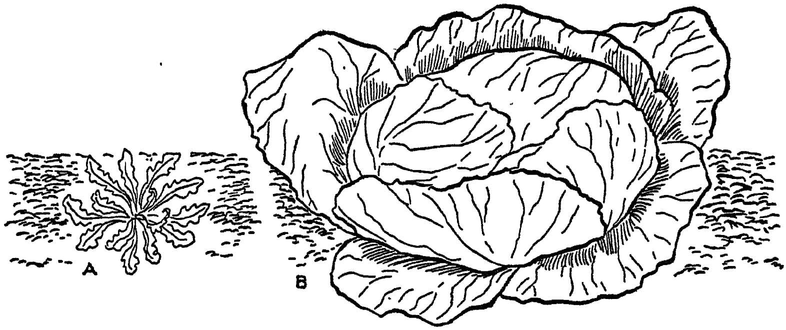

Fig. 176. (a) Wild ancestor of cabbage, (b) modern result

40. WE SELECT THE BEST

AGRICULTURE is the foundation of civilization. Before man domesticated animals and learned how to cultivate plants he was unable to form any settlements or civilizations because his entire time was occupied with wandering in search of food. We do not know when, where, or how the first humanlike savage appeared. Neither do we know when such vital cultural essentials as fire, hunting, cooking, speech, tools, basketry, weaving, pottery, healing of the sick and wounded, art, religious beliefs, and agriculture came into being.

As cultures are the results of human activities, they experience life cycles similar to those of any other associations or communities of living organisms. Tribal cultures originate as inventions and discoveries, or arise from other cultures. They grow and develop as more experience is gained and more efficient techniques are added. They are spread when people migrate from place to place and come in contact with other tribes. In time they mature, and eventually may decline and die as they are replaced by other cultures. They may be added to other cultures as units in more complicated societies, or if separated and rooted in an undisturbed and congenial locality, may retain their characteristics indefinitely. All primitive tribes and former civilizations that have been unable to develop and maintain an assured supply of food and other essentials have disappeared. On the other hand there still exist some backward savage tribes that have maintained their ancestral stone-age way of life until today because they have been able to supply themselves with all the essentials for life by the efficient use of their primitive cultures.

The history of civilization is intimately connected with the history of the products of the plant kingdom and their uses. There is a whole history of vegetable gathering and harvesting extending over many hundreds of thousands of years before the advent of the first person who started to domesticate animals and cultivate plants. Those tribes that added the cultivation of plants to their previously acquired and developed cultures produced the first civilizations.

The cultivation of plants was a great revolutionary achievement that relieved some of the members of a tribe from the duties of food gathering and hunting, and enabled them to have the necessary leisure and peace of mind to invent, discover, and develop other civilizing cultures such as writing, counting, trade, metal work, irrigation, the building of roads and vehicles for transportation, manufacture, and construction.

Every important species of plants which we cultivate today is a living tribute and monument to our prehistoric ancestors who long before the dawn of written history learned the virtues of the best plants; chose the most suitable wild species and profoundly altered them by molding them into desirable varieties; and initiated the arts of breeding, grafting, clearing and preparing the land, planting, tilling, irrigating, fertilizing, pruning, protecting, harvesting, transporting, storing, and processing.

All that modern man has done is to improve upon the techniques that were initiated in the olden days, to find new uses for, and to increase the yields and acreage of, those plants that were handed down to him. It is only within recent times that the search for new, useful wild land plants has been initiated, and new virtues of many forms of vegetation have been discovered. In fact the ancients knew and used many more different kinds of salad, condiment, grain, dye, tuber, root, and herb plants than we do today. Many of those have long since disappeared or degenerated into wild weeds.

Origin of Cultivated Plants

Although modern man uses fewer kinds of plants, he has greatly increased the number of varieties of many important species. By this means he is able to cultivate such vital plants as wheat, corn, rice, oats, potatoes, apples, grapes, tomatoes, and beets in many localities that experience widely different kinds of climatic and soil conditions, and to introduce them to many lands great distances away from their place of origin.

Although most of the plants that man has domesticated still exist in a wild state, it is usually hard and often impossible to fix their place of origin precisely because they were naturalized by ancients in many lands and have been changed from a wild state in regions where they did not originate. Archaeologists and other scholars who study the origin

and history of cultivated plants use many clues in determining the native homes of the cultivated plants and the paths that they took in their travels. We can trace the origin of certain plants by studying fossil remains; areas where species that are closely related to cultivated plants grow in a natural state; regions where cultivated plants grow in a wild state without the aid of man; tombs, temples, graves, and other places where ancients interred human remains together with the tools, utensils, seeds, fruits, and other plant parts that were to be used in afterlife by the departed; uncovered ancient cities, villages, and other prehistoric settlements; primitive drawings, paintings, engravings, and other works of art on walls, pottery, coins, baskets, tablets, columns, and other objects; early historical records; and the many myths, legends, and ceremonial traditions of all countries and religions.

Such important cultivated plants as apple, apricot, buckwheat, cabbage, and taro originated in northern Asia. Southern Asia gave us the banana, cowpea, hop, and certain kinds of oat, rice, sorghum, and sesame plants. We are indebted to China for our barley, millet, pea, peach, pear, peony, chrysanthemum, persimmon, soybean, and tea plants. India is the original home of the citrus fruits, mango, cucumber, eggplant, jute, certain kinds of grains, cotton, tea, and most of our spices. Breadfruit, coconut, grapefruit, yam, and certain kinds of rice originated in various islands of the Pacific Ocean. Arabia gave us the date and fig plants.

From Abyssinia we received okra, coffee, and castor oil. The watermelon plant came from South Africa. The countries bordering the Mediterranean Sea were the original homes of such crops as alfalfa, almond, wheat, radish, grape, olive, carob, lentil, chestnut, lettuce, asparagus, garlic, beet, flax, papyrus, rose and daisy.

Before the exploration of the New World by modern Europeans in the years following the discovery of America by Columbus in 1492, all the plants that originated in the Western Hemisphere were unknown to the Old World. The American Indians who came to the New World many thousands of years ago from Asia did not know any of the Old World cultivated plants. It seems that the ancestors of the American Indians came to the Western Hemisphere before plants were domesticated and cultivated in their native lands, because they did not bring any seeds or other reproductive units with them. Instead, they domesticated and bred the native American plants they found growing wild in the Western Hemisphere. Those Asiatics who settled in North America domesticated certain kinds of plums, beans, many berries, sunflower, pumpkin, squash, tomato, sarsaparilla, and rhododendron plants. The settlers in Central and South America formed great civilizations which were based on corn, potato, cassava, arrowroot, sweet potato, and peanut plants. Other important American plants are avo-

cado, certain kinds of eating chestnuts, cacao, certain species of grapes, sugar, maple, pineapple, sassafras, tobacco, agave, quinine, wild rice, pecan, cashew and other nuts, chicle and rubber, morning-glory, nasturtium, and marigolds.

Plant Introduction

Today many plants are cultivated far from their native lands. Coffee, which originated in Abyssinia, is now extensively cultivated in Brazil. The yield of corn in the Balkan countries is much higher than in its native America. The potato was introduced into Ireland from South America, where it became such an important crop that it is known as the "Irish potato." Bananas thrive better in Central America and the West Indies than they ever did in their native India. Wheat, which originated in the Mediterranean Basin, is now produced mainly in Canada, the United States, Argentina, Australia, the Balkans, Russia, and India. The native home of breadfruit, which is an important staple food of many tropical people, is the East Indies. Its introduction into the West Indies is connected with the famous mutiny of the *Bounty*.

The histories of the exploration, introduction, domestication, and breeding of our cultivated crops are very interesting because they are intimately connected with some of the most important events in man's history. The cultivation of cotton was greatly restricted, and the use of cotton goods limited to small, widely scattered regions, until the invention of the cotton gin in 1793. Today the American Gulf States, Egypt, India, China, Brazil, Russia, and some other countries produce over thirty million 500-pound bales annually. When the British embargo during the Napoleonic wars cut off the supply of cane sugar from Europe, an intense search was made for other sugar-yielding crops. The common vegetable beet, which yields from 2 to 5 per cent of sugar, was selected and bred into varieties that produce over 20 per cent of sugar. Today about one third of all the sugar produced in the world comes from sugar beets. The recent inventions and discoveries in the field of organic chemistry have so greatly extended the use of agricultural by-products and wastes that today tremendous quantities of corn cobs, peanut shells, straw, and other crop wastes which were formerly dumped or burned are the basis of rayon, nylon, and many plastics. These new industries have reached such important proportions that special breeding work has been initiated to produce crops which will yield large quantities of formerly unwanted and discarded products.

The modern histories of the migrations of rubber from Brazil to Ceylon and back to Brazil, and those of the orange from its native home in Indo-China to California are especially interesting.

The hevea rubber trees originated in the tropical rain forest regions of the Amazon River Valley in Brazil. Here for many centuries, the

wild rubber trees were tapped and the white fluid latex was crudely processed into small hard balls by the natives. These bouncing balls were used in many sports. Crude rubber was a curiosity to Europeans and used only as erasers until 1839 when the vulcanization process was discovered. This momentous discovery opened the road to the manufacture of rubber and rubberized objects. By 1873 the demand for crude rubber so greatly exceeded the supply that the price of rubber reached prohibitive heights.

In 1876 seeds of hevea rubber trees were brought to the Kew Gardens near London, England, were germinated, and the seedlings carefully tended in hothouses. When the seedlings became well established they were packed and shipped to Ceylon where they experienced climatic and soil conditions that were similar to their native habitats. After their successful domestication in Ceylon, new high-yielding plantation rubber varieties were bred, and some of these were introduced into Malay, Java, and other Pacific Islands.

By 1910 the first shipment of plantation rubber, consisting of 11,000 pounds, reached the European market. In 1937, 98 per cent of all the rubber used came from plantation trees, and only the remaining 2 per cent from Brazil. In 1934 some of the new plantation rubber varieties that were developed in Ceylon were brought to Brazil, where they are now starting to replace their ancient, primitive low-bearing ancestors.

It is believed that the orange originated somewhere in or near Indo-China. During the ninth century traders carried orange seeds to Persia where the beautiful "golden apples of Hesperides" became so highly esteemed that many legends were written about them. During the Crusades the orange was spread to Syria, Palestine, many parts of Africa, Greece, Italy, Sicily, and southern France. When the Moors invaded Spain from North Africa they brought the orange with them. The early Spanish and Portuguese sailors who explored the newly discovered American continent brought orange seeds with them, and these original introductions grew into wild orange groves in Florida, Brazil, and other warm regions when they were abandoned by the conquerors.

In 1769, when the Spanish missionaries established mission gardens in southern California, they brought many Old World plants which they cultivated with great success. By 1870 the citrus industry in California was becoming fairly well established but there was no satisfactory early and midseason variety of sweet orange suitable to the climate. Introductions were made from Florida, Spain, Australia, and other countries, but these were not well adapted to the climate. In that year the United States Department of Agriculture received twelve sweet-orange trees from a missionary living in Bahia, Brazil. These trees, which bore beautiful, sweet, seedless, easily peeled, large-sized juicy fruits that had distinctive tiny oranges or navels at their freed ends,

originated as a bud mutation on a wild seedling tree which was an offspring of the old Spanish introductions. Trees that were produced from the buds of these plants were sent to California and Florida but did not prosper.

In 1873 a family that was on its way to settle in Riverside, California, received two trees and planted them in their new garden. One of the young trees was killed by a cow. Fortunately the other one was successfully brought to fruiting. This original Washington Navel orange tree proved to be so successful that the fall, winter, and early spring crop of oranges grown in California and Arizona is composed mainly of this popular variety. The original tree from the buds of which tens of thousands of trees were formed is still standing and bearing fruit. It is guarded by a fence, and a tablet in the memory of the settler who first planted this famous Washington Navel tree has been placed near by.

The art of introducing a plant into a region that experiences environmental conditions different from those of its original habitat, and successfully reproducing it and cultivating its offspring in its new home, is called acclimatization. No species can be acclimatized unless its members receive relatively the same climatic, moisture, soil, and other environmental conditions that their ancestors experienced in their native land. The length of day, and warmth, which are influenced by altitude and distance from the equator, the length of the growing season as determined by the date of the last frost in the spring and the first fall frost, the amount and frequency of rainfall, and soil conditions are some of the most important factors which determine the distribution of plant as well as animal life.

When the new habitat offers a more suitable climate, more space and better soil or lack of natural enemies, the invading plant, or one that is being introduced by man, may thrive, and its offspring may multiply rapidly and spread over a large area, even killing off and replacing the natural vegetation. This rapid multiplication and spread will continue until a natural balance is established, or the new type of growth is checked by man. Certain kinds of cacti which were introduced into Australia from Mexico, and pineapples which were brought to Africa from South America, are some of the plants which have succeeded so well in their new habitats that they have replaced many forms of native vegetation. Dandelion, thistle, mustard, and many other imported plants are now obnoxious weeds in our country.

Many plants are introduced into new regions intentionally by man because they are of considerable economic importance even though they are unable to grow in their new homes without his aid. Such plants would be unable to establish themselves, grow to maturity, produce commercial crops, or reproduce themselves without constant, often

very expensive care. In order to cultivate such plants successfully man must constantly perform one or more such tasks as clearing and tilling land, subduing natural vegetation and imported weeds, affording protection from frost, winds, and injurious plant and animal parasites, irrigating, increasing the fertility of the soil, neutralizing acid soils, and removing alkali and other harmful factors.

One of the most significant differences between man and practically all other forms of life is that he has been able to change environmental conditions and to domesticate and breed those plants and animals which fit his needs, instead of being forced to change his ways to fit nature.

Many kinds of cultivated plants and domesticated animals have been so greatly changed by man that they hardly resemble their ancestors, have lost their ability to grow anywhere, and are unable to reproduce themselves without his aid. After having domesticated plants by selecting the most suitable kinds, protecting and cultivating them, the ancients started to form better kinds of plants and animals to fit their needs. Those prehistoric cultivators who selected the best plants and crossed them with suitable relatives initiated the art of breeding. This art was carried to such a highly advanced state by the time that written historical records started to be kept that in many cases it is extremely difficult to distinguish the original ancestors of some of our cultivated plants (Fig. 176).

Indian corn or maize is considered to be the very first hybrid plant to have been intentionally bred by prehistoric man. It is so far removed from any other plant that no species closely resembling it has ever been discovered. It is unable to reproduce itself or grow anywhere without the aid of man, and represents one of the highest achievements in the domestication and breeding of vegetation. Many ancient New World civilizations were so dependent upon corn that when the conditions changed so that the cultivation of this crop was hampered the civilizations degenerated and disappeared.

The male tassels of corn plants start to produce large quantities of pollen several days or weeks before the female silks or stigmas are formed. In primitive civilizations, this useless early pollen was gathered and processed into a mush that sustained the people long before the main crop was ready for harvest. The delicious milky, sweet, unripe kernels were used as food and saved the people from famine when the previous season's crop was low or when the winter was unduly long and the reserve supplies had been used before the harvesting of the main crop of the current year. Even the smut disease (Fig. 114) which attacks corn in the summer was a highly prized mushroomlike delicacy which the Indians ate with relish.

The attractive kernels which range in color from white through yel-

low, orange, red, blue, and purple to black do not separate from the cob on ripening, and the cobs can, therefore, be strung up to dry, thus easily solving the storage problem. As the kernels retain their vitality for ten or more years, those of previous seasons can be used as seeds if the current season crop fails.

The corn plant cannot exist without man because the plant is completely unable to separate and scatter its seeds, and when an entire cob is covered with soil all the kernels germinate together and have no room to grow. Unlike other cereals, which are sowed broadcast and planted so closely together that they do not permit the growth of weeds, the roots of corn plants must be given room and the space between the plants must be kept free of weeds by manual or mechanical tillage.

The aim of modern plant breeders is to form clones, strains, races, and varieties whose members produce large, uniformly standardized, high-quality crops of desired taste, size, shape, weight, texture, and color; come into bearing at required seasons; grow well in desired localities; germinate, grow, and ripen at the same time so that all the farm and garden operations from planting through harvesting can be efficiently performed on a large scale; can be propagated with ease; can withstand frost, drought, wind, dampness, alkalinity, acidity, and other environmental hazards; are immune to harmful diseases and injurious animals; produce crops that can be handled, packed, shipped, stored, and processed without bruising or deteriorating; and have other desirable features.

In selecting and propagating parents that have these qualities, and in breeding them to produce better progeny, certain undesirable or useless natural characteristics have been eliminated, and those traits which are desirable have been enhanced. Some plants which can be propagated by asexual means and are cultivated for their roots, tubers, stems, foliage, flowers, and seedless fruits have lost their ability to produce seeds. Farmers and gardeners who cultivate these consider such a loss to be beneficial because the production of seeds weakens plants and depletes soils, and consumers prefer seedless fruits and large, unusual, long-lasting flowers. Plant breeders on the other hand consider such a condition to be an irreparable loss because they are unable to improve upon existing non-seed-bearing plants, and if the clone or variety degenerates or is lost for any reason, no replacement can be made.

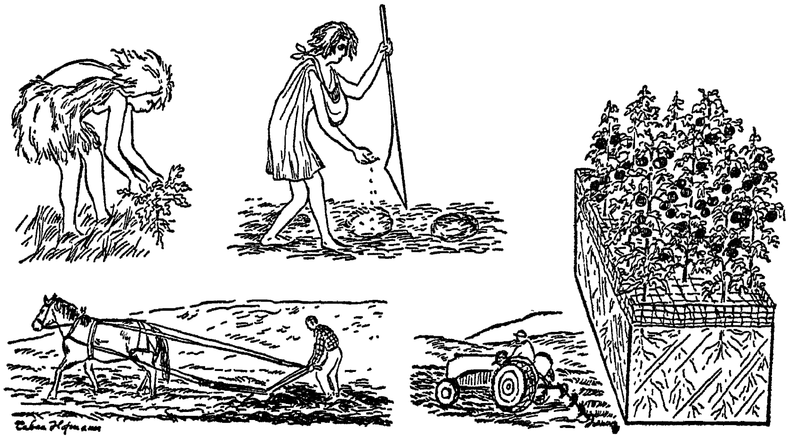

Fig. 177. Stages in cultivation of plants

41. EXPLOITATION OF PLANTS

WHEN we go out into the woods or fields and pick wild flowers, blackberries, mushrooms, and nuts, we practice the most ancient of man's cultures—that of gathering. When, during our walk, we dig up a beautiful bush, and on coming home carefully plant it in our garden, take care of it, then cross it with another plant and multiply its hybrid offspring, we perform some of man's highest activities—the domestication and controlled breeding of another living organism. Between these two extremes there are multiple ways in which man exploits plants.

In all human endeavors man decides what he will try to do, and his physical, biological, and economic environments determine what he can accomplish. In general, the lower the civilization, the more dependent man is upon nature, the more he suffers from natural hazards and is forced to wander in search of congenial locations to supply him with food, water, clothing, and shelter. The better man is able to control his environment and other living organisms, the less dependent he is upon natural hazards, and the more firmly he is fixed to the soil, the higher is his civilization.

The simplest kind of exploitation consists of gathering plants and plant parts with the hands and eating them where they are found. In this type of activity, which is the most primitive of all, man does not need any cutting tools or carrying receptacles. In the next stage of advancement man uses a stick, bone, or the horn of an animal to knock

down the fruits he cannot reach and to dig roots from the ground, and sea shells, sharpened flint stones, and tapering bones to cut plants and skin animals. Man's first discovery was the use of his hands, and his first invention was the addition of an extension to his hands. It is believed that his next great discovery was the use of fire, and his second great invention was some sort of carrying device or receptacle.

Until he could control fire man was unable to eat meat, and until he learned how to carry and hold water, and cut large heavy objects into small pieces, and hold and carry them in some sort of container, he had to eat and drink wherever and whenever he found food and water. When man first started to use a large shell, leaf, empty fruit, the skin of an animal, or a hollowed log as a means of carrying and storing small objects and fluids, he was able to save what he did not need at the moment and use it at a later time.

We still exploit some plants by simply cutting down or gathering the plant or plant parts of certain types of wild, natural growing vegetation in their native habitats. With modern techniques, great quantities of lumber, cork, cinnamon bark, coconuts, gums, and many drug and other plants are gathered without being cultivated. Little by little, as the natural growth becomes depleted and devastating exploitation or mining becomes impractical and expensive, this type of exploitation is replaced by a planned economy in which the best plants are domesticated, and high-yielding varieties are bred, multiplied, planted, cultivated, and harvested under controlled conditions.

Another primitive type of plant exploitation consists of using animals to convert otherwise useless vegetation into food, fiber, bone, skin, leather, fur, and silk. The domestication of animals probably started when the early hunters found that animals group themselves in herds, and that each herd lives under the domination of its male leaders, who protect the herd and lead it to green pastures. By following and directing the herds the nomads tamed them and became shepherds and grazers. Modern herders use woods, plains, and pastures as natural feeding grounds, and in addition cultivate various grasses, alfalfa, corn, clover, and other crops especially to feed their animals.

While man was studying animals and their habits and was a hunter and a fighter, woman's studies in vegetation were constantly contributing to the welfare of the group, and laying the foundation for the brilliant future and science of the cultivation of plants. Every temporary shelter became her laboratory for investigation into the plant world. Women learned the nature and use of fibers by observation and experiment. Basket and mat making, the use of the loom for weaving, and pottery making became her domain. She was the first to learn the medicinal values of certain herbs and roots, the uses of dyes and narcotics, and the beautifying qualities of perfumes and cosmetics. Her knowl-

edge of food plants was of primary value to the tribe and the ultimate determining factor in civilization.

The nomads roamed from place to place in search of new feeding and hunting grounds, and followed the seasons and the food to satisfy their ever-pressing hunger. Man's food was always composed of whatever he could find that his stomach would accept. It was horticulture which bridged the gap between the early harvesters and the beginnings of agriculture. This art consists of the cultivation and care given to individual plants in greenhouses, gardens, orchards, and parks in contrast to the attention given to the cultivation of field crops, maintenance of pastures, and exploitation of forests. The earliest stages of horticultural evolution took place when certain favored plants were singled out for protection and care because of their superior fruits, seeds, bark, leaves, wood, and roots. In time temporary shelters were erected in localities where the selected plants grew, and several weeks were spent every year in gathering and feasting at that place.

Even today many valuable plants are protected and tended in their natural habitats without being planted or cultivated. The sugar maples in New England are carefully thinned and pruned to assure large seasonal flows of maple sap for many years while the trees are productive, and yield long, straight, unknotted logs of highly valuable lumber when they are cut. Unsightly, poisonous, and otherwise undesirable growths are eliminated from various sections of public and private forests and woods to form pleasing landscapes, wide vistas, beautiful parks, enjoyable picnic grounds, and healthful vacation resorts.

The cultivation of plants probably began when man started to notice that certain seeds which fell on disturbed ground in some mysterious fashion grew into new plants. In bringing seeds in baskets and pots to bury with a corpse some of them might easily have spilled out and scattered over the fresh earth. After coming back to a locality where they had eaten or carried fruits and seeds the nomads must have found some new plants growing on top of refuse heaps, along trails, and near watering places. On digging out roots, tubers, and underground stems some parts were invariably cut into small sections and accidentally replanted in well stirred soil. In time the early savages would find a dense colony of new plants growing in that region. By such accidental means the early gatherers must have realized the significance of seeds and vegetative propagation, and in time learned that when seeds and certain roots, tubers, and stems were placed in the ground at desired spots they would grow into the same kinds of plants bearing the same crops as their parents.

Magic and spirits played a great role in early agriculture. Appropriate ceremonies were made for planting and harvesting. For long periods it

was believed that some person had to be buried before a crop could be sown. Many primitive and barbaric savages still believe that there is an association between the burial of a person and the plowing and sowing of grain. Man could not handle woman's tools such as the digging stick, the hoe, and the sickle. His stone ax was the weapon of his domain. Since woman was the fertile one, she naturally planted and tended the crops.

This relationship existed as long as the cultivation of crops involved only her simple tools. When the wheel and plow were invented and domesticated animals started to be used the conditions changed. Man was his first beast of burden, his own draft animal, first as a voluntary worker, then as a slave of conquering people.

During the period that man was making his first steps in agriculture, he discovered that certain wild grasses, which produce large crops of nutritious grains that can be stored for many months, could be sown very closely together and left to fend for themselves from the time that they were planted until they were ripe for harvest. This great discovery enabled him to produce large crops of food and still wander about in search of other food, hunt, domesticate and graze animals, and perform other tasks.

Various forms of nomadic agriculture in which land is not permanently or continuously occupied by cultivated plants have been practiced by all people throughout history whenever a small population occupied a large area of land. In this type of farming new clearings are made by cutting and burning the natural vegetation. The land is then prepared for planting, and after growing one or a few crops the land is either completely abandoned and reverts to its natural state, or is left to rest for several years, then cleared again and replanted.

As primitive men learned how to produce crops continuously on the same plot of ground and increase the food supply, home sites became more permanent and larger groups began to live together. Men ceased to be wandering hunters, nomadic herders, and roving gatherers, and started to develop small permanent villages built of real homes and shops. Thus group living came into existence. Men learned how to cooperate with one another and to obey certain laws which the group decided were essential for its safety and comfort. Slowly, organization developed into government.

During the beginning phases of agriculture, plants were taken directly from the surrounding vegetation. Through countless generations of selection of the better plants for seeding, better and larger crops were produced. As the regions became more productive the populations increased. Centers of civilization grew up about the first planted fields in fertile valleys, along the banks of lakes, and in other suitable local-

ities. Our modern civilizations are merely enlarged, and more complicated and industrialized villages.

As the basis of all civilization is the soil, the origin, growth, and well-being of every human community depend upon the productivity of the land. Since permanent agriculture was initiated, physical, biological, and economic factors have limited the distribution of man and his cultivated crops and determined the farming systems developed. Some of the most important physical features are: the temperature and duration of the frost-free season; the amount and frequency of rainfall, snow, hail, and wind; the lay of the land, whether mountainous, hilly, rolling, flat, rugged, rough, or stony; the degree and direction of the slope; depth of water table, and the character, fertility, ease of cultivation, water-holding capacity, and depth of the soil.

About 6 per cent of the land surface of the earth is unable to support any form of plant life because of extreme cold or drought, lack of soil, alkalinity, and acidity. A large percentage of the land is not cultivated because it is too steep, rough, rugged, and stony; lacking in sufficient water; rich in iron ore, copper, sulphur, and other minerals; occupied by forests, jungles, roads, and settlements; and not accessible to markets due to lack of transportation facilities. Whenever feasible men have modified certain unfavorable physical features by terracing, contour or strip planting, irrigation, drainage, tillage, soil amendments, fertilizers, windbreaks, outdoor heaters, mulches, and various other devices.

The systems of farming that are practiced in each region depend upon physical, biological, and economic factors, and also upon the density of population, and the state of social economy, or the degree of culture and civilization of the people. In countries where the population is small and widely scattered over a wide area, and where the products of hunting, grazing, fishing, and gathering are abundant, man has perfected his agriculture less than in regions where the population is dense, and where nature is not bountiful.

Agricultural systems range from a subsistence or self-sufficient level, whereby the cultivator produces everything that he needs on his own farm, to the cultivation of a single highly specialized crop such as bananas in the place best suited for its growth, which may be several thousand miles away from the market; and from an extensive culture that covers many square miles of territory and requires little or no attention between the time of planting and harvesting operations to extremely intensive or artificial enterprises that may occupy a few square yards of greenhouse space and demand constant attention.

The simplest type of subsistence farming is practiced by barbaric

tribes who live in jungles and other suitable localities. A highly industrialized type of self-sufficiency has been reached by farmers in certain humid American, Scandinavian, and European regions. A typical farmer in the corn belt of the United States grows on his farm all the feed and forage for his animals, and almost all the food that he needs. In addition he raises one or two cash crops, fattens animals, and may produce milk, poultry, eggs, and other products for sale.

Such important crops as bananas, cacao, sugar cane, coffee, pineapples, rubber, and tea are produced on plantation farms in certain hot and humid tropical regions because they require a long growing season and a great deal of heat and moisture. The main tropical plantation farms are situated in certain parts of Asia, Africa, Central and South America, the Caribbean region, and Hawaii. Although these regions are unhealthy and otherwise unattractive to the highly civilized people of the world, they are very beneficial for plant growth and highly productive. Many plantation farms are tremendous enterprises that embrace as much as fifty thousand acres of land or more; employ hundreds of native or imported laborers; are serviced by hundreds of miles of canals, roads, small- or standard-gauge railroad tracks, and ships; and require extensive storage, processing, and distributing facilities. The capital for such gigantic enterprises is supplied by the manufacturing regions where the crops are consumed.

The largest, most densely populated, and most intensely cultivated regions of the world are situated in the monsoon climatic belt which extends through a large part of India, China, Japan, and the East Indies. In the winter the prevailing winds come down from the cold polar regions and the rainfall is slight, seldom exceeding an inch in any single month. In the summer, on the contrary, the hot, water-laden monsoon winds come from the oceans and bring abundant moisture which may deluge the land with fifty or more inches of rainfall monthly. The population of most monsoon regions is organized into small farm villages consisting of from fifteen to about a hundred families. Each family has several tiny, leveled fields or terraced plots used for cultivated plants, and a small section of hilly land, a part of which is covered with grass. A portion of the rough land is used as pasture, another part is covered with woods that furnish fuel, and the remaining portion is planted in fruit trees and in mulberry trees, the leaves of which feed the silk worms.

The staple food of all Asiatics, Filipinos, and other Oriental people who live in monsoon lands and other warm humid regions is rice, which is the main food of over half the population of the world. This crop is admirably suited to those climatic conditions because it requires a great deal of water during the growing season, and a dry period when the rice is ready for harvest. Other important crops are wheat, barley,

vegetables, beans, millet and grain sorghums, which are used for food, and cotton, silk, jute, and Manila hemp, which provide the large amounts of fiber which the people use to clothe themselves and for export. Cotton is grown in most monsoon lands; the silk industry is centered in China and Japan; jute is an important Indian crop; and Manila hemp comes from the Philippines.

The semitropical or humid subtropical regions of the world have climates that are somewhat similar to those of the monsoon lands, but experience greater contrasts. During the summer months there is more heat and less precipitation, while the winter months are very moist and sometimes cold. The growing season lasts about two hundred days, but occasional cyclonic storms and frost devastate the vegetation. This type of climate is found in the southeastern parts of the United States, Africa, and Australia, and in the Rio de la Plata region of South America. Grazing, modified forms of plantation farming, and intensive cultures are practiced. With the expansion of transportation facilities these regions are being developed into important agricultural and industrial centers. Cereal grains, hay, cotton, tobacco, early fruits and vegetables, pineapples, and subtropical fruits are among the most important crops cultivated.

The Mediterranean Basin, the southwestern parts of the United States and Asia, South Africa, and certain sections of Latin America, China, Japan, and Australia have subtropical climatic and soil conditions. These regions experience a hot rainless summer, and a warm, humid or arid winter. Wherever the natural rainfall is sufficient or water for irrigation is available, the rich alluvial soils which border the rivers, the fertile valleys, and the terraces built on the lower slopes are intensively cultivated and used for the growth of alfalfa, early fruits and vegetables, flowers, cotton, tobacco, and various tropical and subtropical crops such as artichokes, almonds, citrus, dates, and figs. The cooler slopes which receive some rainfall are planted in olives, cereals, and grapes. The mountainous sections, drier lands, and irrigated pastures are used for grazing.

The most industrialized people of the world, and those having the highest cultures and the most complicated civilizations, live in temperate lands that experience a diversified climate that is divided into four seasons: a warm rainy spring, a hot humid or arid summer, a cool dry fall, and a cold humid winter. The main food crops grown in the temperate regions are the grain cereals; potatoes and sweet potatoes for starch; beets for sugar; tobacco as a stimulant; hops for beer; various legumes such as peanuts, beans, and peas for oil and proteins; poppy, sunflower, flax, and corn for oil; many vegetables, and fruits. The most important forage crops are corn, timothy, Kentucky blue grass, sorghum, and such legumes as alfalfa, cowpeas, and several kinds of

vetches and clovers. The products of various plants such as flax, peanut, soybean, and corn are used in the manufacture of natural and artificial fibers, and for many other industrial purposes.

Five types of farming systems have been developed in temperate lands: semi-arid, mixed, dairy, orchard, and garden or truck farming. The most important crop in the semi-arid regions is wheat. Wheat is the favorite food in the Temperate Zones of the world because it is one of the most nourishing cereals and can be made into a deliciously palatable white bread. When we use such expressions as "our daily bread," "the staff of life," and "the marrow of man," we invariably think of wheat. So many varieties have been formed, and it is so widely grown, that there is not a single month of the year when wheat is not harvested some place on the earth's surface. In the great wheat-growing sections of the United States, Canada, Russia, Argentina, and Australia this is the only crop grown, and the planting and harvesting operations are completely industrialized. The tremendous level or rolling plains are plowed, harrowed, fertilized, and planted by powerful machines in one operation, and the harvesting is done by a single combine which cuts, threshes, cleanses, grades, and bags the grain, and by a baler that bales the straw while being pulled by a tractor across the fields. Airplanes are used to treat the plants against diseases.

While the better lands are devoted to the growth of the major cereals and other high-yielding, well-paying crops, the poorer fields are often planted in the minor cereals that produce well on marginal, rough and hilly lands which experience climatic conditions too severe for other crops. Millet is probably the first grain to have been domesticated, and the invention of the plow is credited to the primitive ancient farmers of China and India who cultivated this crop. Barley probably appeared before wheat, and it is believed that wheat was a weed in barley fields before it was domesticated. Barley is universally used in the manufacture of malt for beer. It has the greatest climatic and soil range of all the cereals because it is very resistant to drought and matures quickly. Other important Temperate-Zone grains are rye and oats.

When wheat or any other crop brings in a high price it can be planted in so-called marginal lands, which are more or less arid and infertile and do not produce high yields. When such unsatisfactory lands are cropped for many years in succession they may dry out completely and the valuable top soil may be blown away by winds, or washed away by heavy rains causing disastrous erosion and great suffering. In some semi-arid regions the yearly rainfall is so slight that it is necessary to accumulate water in the ground for two or more years before the soil is able to produce a satisfactory crop. Such a cropping system is called dry farming. During the time that the land remains uncultivated or

fallow it is occasionally plowed and harrowed in order to discourage the growth of weeds and reduce water loss.

Wherever the soil and climatic conditions are suitable and the cost of the land and taxes are not prohibitive, mixed farming is practiced in most temperate lands. In this type of farming many kinds of agricultural activities are undertaken on a large scale, and a high standard of subsistence living is achieved by the farmer and his family, who work the farm with little or no hired help. The individual farm is a diversified establishment producing a large variety of products. Sections of the farm that are unsuited for the raising of crops are kept in permanent pastures and woodlots. A certain amount of milk and poultry products, fruits and vegetables, are produced for home use, and in some localities larger quantities are raised for sale.

The economy of practically all mixed farms is centered around corn, which is the king of cereals, and the most important stock feed of the world. Before the sixteenth century, this crop was unknown to the European World. Since the early colonists settled in America and learned the cultivation of corn it has been introduced all over the world. The Arabs say that the palm has "as many uses as there are days in the year," but the products of corn plants are utilized in countless ways, and new uses are constantly being discovered. In no matter what form we use or eat an animal product we are utilizing some type of converted corn. Furthermore, about one-fourth of our corn crop is used in making many industrial products. The importance of corn is so great that the value of the annual crop is over two billion dollars, more than double that of wheat.

In the cooler and more moist regions of the temperate lands a specialized type of mixed farming, called dairying, is practiced. In dairying forage crops are converted into milk. This is probably the most exacting and arduous type of agricultural activity as it requires a great deal of expert knowledge and continuous daily labor. It is very remunerative because a milch cow can transform a given quantity of feed into highly prized and vital human food more cheaply that can beef cattle, hogs, and sheep.

Countless varieties of vegetables have been domesticated and improved and are grown in commercial and home or kitchen gardens to provide bulky food and maintain a balanced diet for man. Some, such as potatoes, onions, cabbage, beets, beans, and turnips, are handled as field crops by farmers and specialized growers, and are considered to be horticultural crops by market or truck gardeners. Many vegetables such as beans, cabbage, onions, and radishes are not exacting in their soil and climatic requirements and can be grown in practically every region of the world with little effort. Others, such as cauliflower, celery,

endive, asparagus, and various melons, require special conditions and care. Those that are tender are germinated and raised in special greenhouses and hothouses in colder lands, and either transplanted outdoors or retained and matured under shelter.

Until recently nearly all fresh vegetables and fruits used by the large urban centers were grown in truck farms situated near the cities they served, and during the "off" season no fresh produce was available. Today, favored regions, such as Yalta on the Black Sea, certain areas of the Mediterranean Basin, and sections of the United States, that enjoy optimum climatic and soil conditions for gardening, produce and ship such large quantities of perishable vegetables, fruits, and berries that the people living in the colder temperate lands receive a steady supply of fresh, canned, dried, and frozen produce all year round.

Arboriculture is the science of growing and cultivating fruit, nut, forest, ornamental, and other kinds of trees. It differs from all other forms of agricultural activities in that long-lived trees, vines, and shrubs occupy the ground for many years without being removed, while all the field crops, and most vegetables, are sown anew after each harvest, or after a period of three to seven years.

Since trees require several years to reach maturity and then produce crops regularly for a great many years, special care is taken to select the very best budlings, seedlings, and cuttings of suitable varieties from certified parents. The soil conditions, especially in regard to texture, depth, fertility, acidity, and drainage, as well as climatic conditions, exposure, and topography, are of paramount importance because trees once planted, cannot be replaced without the loss of much effort, time, and capital. Where irrigation is required, detailed attention is given to leveling or terracing the land and laying out irrigation lines before planting.

The culture of fruit trees is called pomology. In relation to their climatic requirements fruit, nut, and other tree crops can be classified into tropical, subtropical, and temperate groups. The most important tropical tree crops are coconut, mango, breadfruit, rubber, quinine, coffee, tea, cacao, cinnamon, nutmeg, pepper, and vanilla, pineapple, and banana which are not woody trees, but long-lived perennial herbs. The subtropics furnish us with dates, citrus fruits, fig, avocado, almond, olive, and pecan. The pome fruits, which embrace the apple, pear, and quince, and such drupe fruits as cherry, peach, and plum, are the most widely grown temperate fruits.

Floriculture is the art of cultivating flowering and certain other kinds of plants for ornamental and industrial purposes. Commercial florists grow their crops either under glass or outdoors, and their main activities consist of forcing plants to bear cut flowers for sale in the wintertime, and for special occasions such as Easter, Mother's Day, Thanksgiving,

and Christmas; to produce various kinds of bulbs, ferns, and other types of decorative vegetation to be used as potted indoor house plants and for outdoor landscaping purposes; and to grow flowering plants for the perfumery industry.

Landscape gardening is a very important horticultural activity in which various arts and sciences are applied to improve the land in such a manner as to form a pleasing, practical, and useful living picture. The traditional tales and writings of all people, no matter what their religious beliefs may be, usually begin with a legend about a marvelous garden. In the Holy Scriptures the Garden of Eden was the terrestrial Paradise where our first ancestors, Adam and Eve, are said to have lived an eternally happy life, ignorant of toil, pain, or death. God made all kinds of plants that man needed to grow forth from the earth, and all the trees the fruit of which was good to eat, and pleasant to look upon. In the middle of the garden stood the tree of the knowledge of good and evil, and the tree of life. Later accounts have added the water that would be needed, the stream which had its source in Eden, and from which four other rivers flowed. In this garden beasts lived together in peace. This garden gave much refreshment both from its fruit and its cooling shade, and tradition says that there God himself walked in the cool of the evening. Another ancient legend relates the story of the Garden of Hesperides, from which golden apples were stolen by Hercules who slew the dragon of a hundred fiery heads that guarded the sacred grove.

It is believed that man's first gardens consisted of collections of such herbs, bushes, and trees as furnished him with useful products. The culture of ornamental plants for decorative purposes did not take place until people became sufficiently civilized to have the required leisure, and to develop a taste for beautiful surroundings. One of the seven wonders of the ancient world consisted of the famous suspending or hanging gardens of Babylon. These were in the form of a terraced pyramid that covered about three acres of ground, and the highest terrace was about seventy-five feet high. The upper terraces were supported by hidden pillars and walls that were about twenty feet thick. Each terrace was covered by a layer of lead on which several feet of soil were poured. Water brought by aqueducts from the Euphrates River was raised to the highest levels by pails through hollow pillars. Unfortunately no records have been found to tell us what kinds of plants were grown.

Many ancient Assyrian, Persian, Peruvian, and Mexican gardens were also suspended from pillars or consisted of terraces that were cut from the hillsides. The remains of many ancient gardens have been uncovered in Egypt, Assyria, China, Japan, India, Greece, Italy, North Africa, and Spain. The first gardens for instruction purposes were

started by monasteries and universities. There medicinal plants and other types of vegetation were grown and studied. After the Middle Ages and during the seventeenth, eighteenth, and nineteenth centuries distinctive types of formal and informal landscape architectural designs were developed in Japan, China, France, Italy, Spain, England, and America.

Various kinds of water plants or aquatics are grown in lakes, ponds, streams, pools, and aquariums. Aquatic plants play an important biological role that is very beneficial to man because they furnish fish with oxygen and use the carbon dioxide gas which is released by the animals for their life activities. The fish, supplied with the oxygen, are able to thrive and devour the eggs of mosquitos and other pests, and the spores of varied disease-producing fungus growths.

Many methods of exploiting plants and plant products by highly specialized and artificial means have been developed through the ages. All kinds of outstanding plants are especially bred, propagated, and raised by fanciers, commercial establishments, and amateurs for advertising and exhibition purposes. All over the world garden societies hold exhibitions at suitable times where qualified judges use specially devised scoring methods to select the prize winners. Educational and research institutions breed and raise plants under carefully controlled conditions in laboratories, under glass, and outdoors to study all phases of plant life. Commercial mushroom culture is practiced in many regions in especially constructed or natural caves and cellars where the suitable feeding medium, humidity, and temperature are carefully maintained.

The raising of bees or apiculture; the culture of silkworms or sericulture; the production of poultry products or aviculture; the raising of grapes and the manufacture of wines or viticulture; forestry or sylviculture; the milling, textile, tanning, chocolate, and brewing industries; and the manufacture of cider, cosmetics, drugs, and yeast are some of the industrial activities that are directly dependent upon agricultural products.

The most artificial method of growing land plants is in tanks of nutrient solution, a science known as hydroponics. Although biologists have been growing plants in solutions for several hundred years for scientific purposes it was not until very recently that this method started to be employed for commercial purposes. During the recent war this method of raising plants was adopted by the armed forces in many isolated soilless Pacific islands, and proved to be a great success in furnishing the men with fresh vegetables without the use of soil or rainfall.

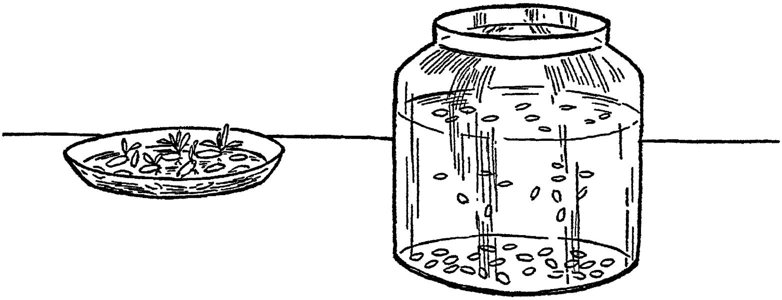

Fig. 178. Testing of seeds

42. PRODUCTION OF SEEDS

IN former days each tribe and every immigrant who settled in a new land brought his own seeds from his homeland and introduced the crops he knew into his new location. These early settlers, by a slow and costly process of trial and error, in due time found out which plants were suited to their new homes, which plants failed to grow or produce satisfactory yields, and which of the local plants he found growing wild or being cultivated by natives were suitable to his needs. The modern cultivator has been relieved of this type of costly, time-consuming, and often very discouraging guesswork.

The federal, state, and municipal governments; the many public and private experiment stations, research laboratories, trial grounds, arboretums, and botanical gardens which are subsidized by public funds, philanthropic societies, growers, shippers, packers, and processors of plants and plant products; and commercial seed growers and nurserymen; all have large well-trained staffs who explore, introduce, acclimatize, breed, graft, and reproduce plants. They gather plants and plant parts from all corners of the world and either grow them under controlled or natural conditions, or preserve them in a dry state in herbaria so as to be able to compare and classify plants from many regions. In addition, they study the physical structure and chemical composition of plants, the activities that go on in living matter and how they can be controlled; problems of growth and development; plant nutrition; control of insects and diseases; soil conservation; cultural methods and tools; new uses for plants and plant products; and other fundamentals and their applications to man's needs. All public and many private institutions supply seed growers and nurseries with new

kinds of plants, and disseminate information through county agents, by various extension services, and by publishing their findings.

The commercial nurseries and seed growers work in close cooperation with the public and private research institutions, and are the main outlets which periodically supply farmers and gardeners with seeds and plants. The most important activity of these commercial establishments is to preserve the existing clones, strains, races, and varieties, and to produce better plants to fit changing economic and biological conditions.

Seeds are perhaps more important to the life and prosperity of a country than any other single commodity because the quality and quantity of every crop produced depend, to a great degree, upon the quality of the seeds which were planted. It has been estimated that more than fourteen billion pounds of seeds are either sown or planted annually in the United States alone. Even a small improvement in this vast quantity of seeds would result in larger crops at little or no additional expense, or the same size crop could be produced on a smaller acreage with less effort and cost.

The vital importance of good seeds was recognized by the earliest cultivators. Many ancient legends describe elaborate ceremonies pertaining to the production, gathering, curing, and preservation of seeds, and tell how the ancients planted their seed-producing plants in separate fields which were given special attention and protection. Many pioneers have died of starvation rather than consume their seeds because they realized that each seed represented the accumulated, untiring, meticulous selection, breeding, preservation, and care given by countless cultivators and breeders, extending back through the centuries to the very first savage who discovered the virtues of that plant and selected the first seeds. All producers of seeds bear a heavy burden of responsibility not only to growers they supply but to all generations of man to come.

Seed-producing plants are grown in localities where their quality can be maintained. Many regions where successful commercial crops are grown are not suitable for the production of seeds. Biennials such as beets, carrots, and turnips must endure cold winters in order to grow vigorous, seed-producing flowering stalks. Such plants as sweet peas and lettuce require a hot dry summer to bear seed while others such as cabbage and cauliflower need a wet or moist summer. Because the production of high-quality seeds requires special soil and climatic conditions and often very careful cultivation and a great deal of manual labor, a certain proportion of our seeds, bulbs, and other reproductive units are grown in England, France, Holland, China, India, and other foreign countries where the environmental conditions are suitable and hand labor is not expensive.

The gathering, preparation, storage, and testing of seeds are highly specialized tasks that require a great deal of experience. If the seeds are gathered before they are fully mature they may not keep or germinate properly, and when permitted to become overripe there may be a large loss due to shedding, or disease and insect injury. As soon as the seeds are gathered they are labeled, and a tag stating their origin, time and place of growth, and other pertinent data accompanies them until they are actually planted in order to avoid all chance of their being mixed with the seeds of other clones, strains, races, and varieties.

In order to protect themselves against unscrupulous dealers, to exchange information by the publication of house organs, and to help and protect each other in various other ways, the reliable seedsmen have formed two separate associations. Dealers in alfalfa, clover, grass, and other farm seeds belong to the Farm Seed Association of America, and those firms that deal in vegetable and flower seeds are members of the American Seed Trade Association. The growers of certain specialized farm crops have local, state, and national crop-improvement associations which stimulate the production of improved varieties. These high-quality seeds reach the consumers through the better seedsmen.

Most vegetable and flower seeds are grown by special growers and farmers under contract with dealers and large producers. Some specialize in one or two crops only, while others grow several kinds of seeds. Seeds for the canning and other processing industries are produced by specialists because the purity of the stock is the first consideration. These seeds are then distributed to the farmers who grow the crops for the processors under contract. Every important vegetable- and flower-seed grower keeps a stock record and has his trial grounds where he grows samples of his seeds to full maturity. Many have their own seed-testing laboratories, experiment stations, and other installations where they personally maintain the purity of their stock, improve upon their own or their competitors' varieties, produce new hybrids, and test new mutations.

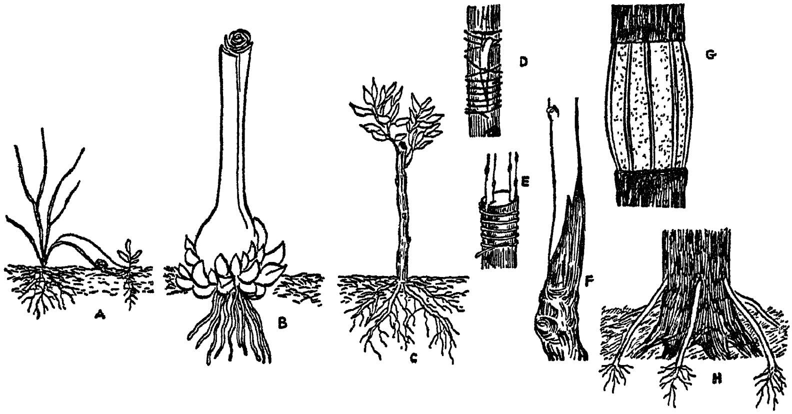

Fig. 179. (a) Layerage, (b) bulblets, (c) cutting, (d) bud graft, (e) cleft graft, (f) root graft, (g) bridge graft, (h) inarch or approach graft

43. PROPAGATION AND GRAFTING

MANY plants are propagated by asexual or vegetative means because they are unable to form fertile seeds or cannot be reproduced true to type by sexual means, or because it is more convenient by this means to produce a large number of uniform offspring quickly and economically from desired proven parents. There are innumerable kinds of natural and artificial vegetative propagating techniques that are used, the choice depending upon the growth habits of the different plants and on local conditions.

A great number of plants reproduce themselves or are aided in propagating themselves by layerage, separation, and division. In these types of natural asexual reproduction methods a small portion of a plant regenerates an entire new individual that resembles its single parent either before or after being separated from its mother plant.

Layerage is a method of inducing aerial buds to form new plants while remaining attached to, and fed by, their parent plants. This is accomplished by covering plump, mature, well-formed buds with damp soil, sand, or some other suitable material. When the new plant is properly rooted, it is cut away from its parent, removed, and planted in a new location (Fig. 179).

Propagation by separation or division consists of removing a fleshy part of a herbaceous plant that contains a growing point, rudimentary root system, and sufficient food, and planting it.

A great many plants are reproduced by cuttage. This method of artificial propagation consists of detaching a portion of a stem, leaf, root, or fruit and placing the lower part in damp soil, sand, sphagnum, mica, water, nutrient solution, or some other medium for the purpose of producing a new plant. Before a cutting can form any new foliage, a root and vascular bundle must be formed to feed it. As cuttage is an artificial method of inducing undifferentiated cambium dividing cells to form root and conductive tissues, the success of this operation depends upon many factors, which are different for each species and variety of plant life. Generally, the younger the cutting the easier it is for its cambium to form root cells. Sometimes special hormones are applied to induce root production, and the cuttings of many plants must be treated with various chemicals to protect them against insect and disease attack.

Grafting is another means of artificially reproducing plants (Fig. 179). This technique consists of uniting the cambium of a desired variety called the scion, or cion, with the cambium of a suitable and compatible receiving plant, which is known as the stock, to form a combination plant or stion. The scion may be a single bud, a twig bearing one or more buds, a terminal shoot, or a piece of stem. The stock may be an entire plant, a complete root system with or without the stem, or fragment of a root. When a single bud is grafted on a seedling the resulting plant is usually called a budling. The primary purpose of forming such a combination is that it is the only means of asexually propagating a desirable variety that does not come true to seed and cannot be reproduced at all, or only with great difficulty, by cuttage or any other vegetative means. Grafting is often employed to give a desired variety a better root system than it naturally has, to produce mature plants sooner, and to advance fruiting. Sometimes plants are grafted to modify the growth of the scion or the stock, to create a plant that bears two or more different varieties of flowers in order to increase the chances of successful cross-pollination, or for the novelty of having more than one variety growing from a single stem.

The success of a graft and the character of the composite plant depend upon some known and many unknown factors. Some of these are the nature of the stock and the scion, the degree of compatibility that exists between them, the effect they have on each other, their comparative age and size at the time the grafting is done, the time of the year that the operation is performed, the manner in which the two different cambium tissues are united, and various environmental conditions. Generally, most members of the same genus are more or less compatible. Orange, lemon, grapefruit, and tangerine can be intergrafted; so can almond, apricot, cherry, nectarine, peach, and plum, as well as apple and crab apple. In some instances the members of two different, but closely

related genera belonging to the same family can be successfully united as in apple, pear, quince, and hawthorn, and tomato and eggplant.

The amount and chemical composition of the food which the scion produces influences the stock to a greater or lesser degree, and reciprocally, the amounts and kinds of water and mineral elements that the stock absorbs affect the scion. The root system of the stock may thus be lengthened or shortened, made more or less fibrous, resistant to frost, disease, and insect attack, its life span lengthened or shortened, and changed in other ways. The size, form, growth habit, branching, hardiness, texture, color, flavor, and other features of the stem, buds, foliage, flowers, seeds, and fruit of the scion may be more or less influenced by the stock.

As soon as the cambium tissues of two different individuals are united an antagonism between the two kinds of protoplasm, cells, and tissues develops, and each kind tries to become the dominant one. The outcome depends upon many factors. A large stem may influence a small root, a younger root may dominate an older stem, a fast-growing variety may subdue a slow-growing relative. Sometimes the antagonism between the two is so great that their protoplasms, cells, and tissues become intermingled, and form various types of distorted hybrid growths known as chimeras. In some cases the cells and tissues of a chimera are not intermingled, but the surface cells of a plant part may be of one kind of plant, and the inner section may be made up of the cells of a different plant. Not all chimeras are due to grafts, but may take place as a result of the intermingling or uneven dominance of two different cells or tissues of the same plant.

As the protoplasm, cells, and tissues at the point of union are more or less intermingled, or cover each other in one or more layers for greater or shorter distances, a composite plant differs at that point in chemical composition, cellular structure, and other characteristics from both the stock and the scion. The farther away from the point of union, the more distinct and normal are the cells and other features of the stock and scion.

In forming a composite plant the quality of the root stock is as important as that of the scion. In order to have a root system whose ancestry, growth habits, and other features are of the highest quality and which will form a strong compatible union with the scion, special root-stock-producing mother plants are bred and grown. Whenever feasible these special plants are either propagated by vegetative means or pollinated under controlled conditions.

Many composite plants are formed by a system of grafting called budding. In this form of grafting only a single bud of a desired variety with little or no accompanying wood is inserted in the stock. More than a dozen methods of budding are employed, the choice depending upon

the nature of the material, the size and form of the tissues accompanying the bud, the size and age of the stock, and the kind of opening made in the receiving stock.

Grafting is different from budding in that a short section of a one-year-old twig is placed on the stock instead of a single bud. There are six general classes of grafting, depending upon the position of the joint upon the plants, called root, crown, stem, top, and bridge grafting, and inarching. There are innumerable kinds of grafts, their names depending upon the methods used to join the scion to the stock, such as whip, tongue, splice, cleft, notch, saddle, veneer, and side grafts.

Many species of the plant kingdom have roots, stems, buds, leaves, seeds, and fruits that contain growing points or undifferentiated meristematic dividing cells that have the wonderful ability to regenerate all the other missing parts and produce individuals that are the vegetative offspring and exact copies of their original single parents. In addition the cambium tissues of two or more plants of many species may be united to build up a new plant by grafting. By the use of layerings, cuttings, divisions, and grafts the cultivation of useful plants has been expanded and diversified, and many new plants that have come into being as mutations or were brought into existence as hybrids may be perpetuated indefinitely.

One of the most important factors which determine the value of a plant is the ease with which it can be propagated. Many excellent hybrids and mutations are reluctantly discarded because they cannot be reproduced true to type by seed, and are too difficult or impossible to propagate by vegetative means. In some cases species and varieties of mediocre quality are grown because they can be propagated with ease. Whenever a desirable plant is difficult to propagate, all possible means, at great expense, are resorted to in order to ameliorate that deficiency, and one of poor quality that can be propagated with ease is changed by breeding and other means to produce superior crops.

Whatever the method that may be used, the main purpose of propagating plants by vegetative means is to ensure a uniformity among offspring. When we remove and graft many buds from one particular navel orange tree, every bud will grow into a tree that will produce fruit similar to that of a parent tree. Any number of cuttings from a particular grapevine, rosebush, or fig tree will grow into new plants producing the same kinds of grapes, roses, and figs. All the offspring that are propagated from one particular parent by vegetative means are duplicates, and we say that they are members of one clone. When growing under the same conditions, each member of a clone will produce the same type of growth, flowers, and fruits as the original parent.

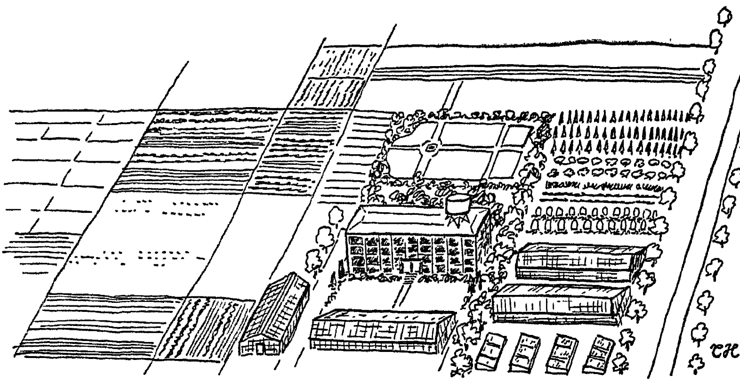

Fig. 180. A modern nursery establishment

44. PRODUCING YOUNG PLANTS

MANY public, private, and commercial establishments, some farmers and gardeners, and a few amateurs improve, propagate, and raise forest, nut, fruit, berry, and ornamental trees, shrubs, and herbs. The establishments and plots in which plants are bred, reproduced, and formed for forest, landscape, orchard, garden, greenhouse, and indoor purposes are appropriately called nurseries.

Such activities require a great deal of time, patience, technical knowledge, and experience. Sometimes hundreds of thousands, even as many as a million or more, seeds from desired parents are gathered, planted, cultivated, and brought into fruiting in order to produce a handful of plants that have the required characteristics, while all the undesirable ones or rogues are ruthlessly eliminated and destroyed. The seeds of the selected plants are sown and the seedlings brought to maturity. The selected plants may have to be interbred or crossed with others and their progeny sorted, planted, and crossed twenty or more times before the desired characteristics are permanently fixed. As certain trees require a decade to bring each generation into maturity, it may take as long as two hundred years to breed a desired slow-growing and maturing plant. Such slow, exacting, time-consuming work can be undertaken only by governments, philanthropic institutions, and large commercial establishments. Of course, when quick-maturing herbs are bred, two or more generations may be produced annually, and a new plant under such conditions may be established in five years or less.

In order to encourage the production and distribution of new hy-

brids and desirable mutations, the United States Patent Office grants a patent to each professional and amateur producer or discoverer of a new kind of plant. This gives the person the right, for seventeen years, to control by license or otherwise the production and sale of the offspring of his new plant "invention." A plant patent does not necessarily mean that the variety is better than others, but merely signifies that it is new.

The primary essentials for successfully propagating plants by seeds are viable, pure, clean, mature seeds of good germinating quality that came from vigorous, healthy, productive parent plants. Tests for maturity, purity, and germination are usually made before sowing. Mature seeds can often be separated from immature ones by placing the lot in water for a few days (Fig. 178). The inferior seed will come to the surface while the good seeds will settle to the bottom of the container. The seeds of many plants require special handling to reduce the time between maturity and ability to germinate, and to assure successful germination. Such short-lived seeds as willow and poplar are planted immediately upon ripening, and those that require a long "after ripening" period are stratified or stored by other means for one, two, or more years. Seeds that possess hard coats are treated with acids and other chemicals, placed in warm water, scratched, filed, or cracked before being planted.

In order to extend the length of the growing season, to grow delicate plants under controlled conditions, and to produce mature plants and crops out of season, plants are started and grown indoors, in greenhouses, hotbeds, and cold frames. Seeds that are germinated indoors and under glass are usually sown in shallow wooden boxes, tins, pots, and other suitable containers.

Greenhouses, conservatories, and hothouses are wooden, steel, and cement-framed structures that are partly or completely covered with glass, heated by artificial means, supplied with artificial light, and ventilated by special movable overhead and side sections. Some very elaborate greenhouses and conservatories have controls to regulate the temperature, humidity, and ventilation automatically.

Hotbeds are shallow outdoor beds of rich earth that are enclosed within more or less permanent wood or cement frames; heated by hot water, steam, electricity, or fermented organic matter such as manure; and protected by movable sashes which support glass, gauze, or some other more or less transparent material. Ventilation is provided by lifting and supporting the sashes at desired heights. Added protection against extreme cold spells may be provided by covering the sashes with straw and other matting. Cold frames are shallow, temporary wooden structures that are covered with glass, burlap, cheesecloth, and other suitable material. When a hotbed is unheated it serves the purpose of a cold frame.

The removal of a plant from its place, transporting it, and planting it in a new location is called transplanting. The best time to transplant any seedling, sapling, or mature plant is when it is in a dormant condition, because at that time all growth activities are almost at a standstill and the shock to the plant is minimized. Deciduous plants are usually transplanted during the late fall, winter, or early spring when they are devoid of foliage. If it is necessary to move them before their leaves have shed in the fall, they may be defoliated by artificial means. For convenience in handling, their tops may be cut back and the soil shaken or washed off.

Most evergreens experience several alternating growth and dormant periods annually, and are dormant during the early spring, late summer, and fall. As evergreens retain their foliage and require a continuous supply of water their roots must be covered with damp soil. In order to prevent soil from shaking off and exposing the roots the ball of earth is enclosed within burlap, straw, and other protective coverings.

After the seedlings are removed from their seedbeds, and before they are prepared for replanting, they are closely examined and all those that are not true to type, small, weak, thin, crooked, diseased, and unsuitable for other reasons are eliminated. Certain seedlings that are not true to type, but show promise of being able to develop into desirable plants, may be planted in special trial plots. There are definite standards in the size, shape, color, branching, and straightness of roots, stems, and leaves that are followed in grading and sorting the various species and varieties. Seedlings with thick stems are usually preferred to those that are too long and spindly. Sometimes as many as 15 per cent or more of the seedlings may be eliminated during this first inspection. At each subsequent time that the plants are transplanted they are examined, the unsuitable ones eliminated, and those that are retained graded. Each plant or lot is always accompanied by labels which show the scientific name, parentage, time of sowing, time of inspection, grade, and other pertinent data.

Some gardeners, especially in restricted areas, require dwarf plants. Dwarf forms of many species may occur naturally or they may be developed through plant breeding, by grafting suitable varieties on root stocks that have a dwarfing effect, or by mechanical manipulation which consists of a carefully studied system of pruning, training, watering, and feeding plants. The Oriental art of dwarfing trees to such an extent that they may be grown in miniature gardens in small pots or plates is called Bon Sai. This technique has been developed to such a degree that trees several hundred years old are kept at heights not exceeding a foot.

Some nurseries do their own propagating, and others buy young stock from propagators, collectors, and other sources. They raise this

stock to maturity and then sell their plants to dealers, or directly to consumers. Many nurseries have experienced gardeners, landscape artists, tree surgeons, pest controllers, and other specialists who lay out, plant, and take care of private and public parks, gardens, and individual, highly prized specimen plants. The commercial nurserymen have a strong organization known as the American Association of Nurserymen, which holds annual meetings and publishes a report. In addition there are several periodicals that are devoted to the nursery business.

In order to prevent or delay the establishment of plant pests and diseases in areas where they do not exist the federal and state governments have passed plant quarantine laws that regulate the importation of plants and plant parts into the United States, and their movements from one county or state to another. Anyone who intends to purchase plants from a distance or to ship plants and plant parts out of his immediate neighborhood should secure the latest information about the plant quarantines affecting his region and the variety in question from his local, state, or federal plant quarantine authorities. All plants sold by reputable nurserymen are guaranteed to be free of pests and diseases. Many commercial nurseries have plots scattered in several locations in order to be able to control pollination, insect and disease attacks, and produce healthy, pure, well-formed, disease- and insect-free plants of high quality.

Fig. 181. (a) Irrigation, (b) contour-strip-rotation cropping

45. BASIC FUNDAMENTALS

NO other human activity is so restricted by traditionally imposed conservative customs, bound by so many superstitious observances, and at the same time practiced in such a wide variety of seemingly contradictory ways as is the art of cultivating plants. On the one hand all basic farm and garden operations are of immortal antiquity, having been passed down from father to son for countless generations; on the other, each of the hundreds of kinds of plants that are cultivated by man require special cultural methods in different regions, and at their varying stages of growth. Furthermore, the soil and other environmental factors on any two plots of land differ to a greater or lesser degree. In addition, no two people have exactly the same temperaments or do the same things in a like manner. Often the methods used by two successful neighboring farmers growing the same crops may seem to be contradictory.

Although there are so many conflicting ideas as to which are the best methods of preparing, tilling, irrigating, draining, and increasing the fertility of the soil, and planting, training, pruning, rejuvenating, and protecting the same plants in the same region that no person can tell another how to cultivate his land and manage his enterprise, several basic fundamentals can be set forth.

The factors governing the successful raising of any individual plant or the production of any crop may be divided for convenience into three general groups: those which have to do with the inherent character of the plants themselves; those which are related to the environment; and those which are determined by the grower in the cultural methods he uses. No plant can be forced to grow where any environmental condition or cultural practice does not permit or retards the normal functioning of the protoplasm of its cells and of their genes, plastids, inclusions, en-

zymes, cell walls, and other living and nonliving parts. Each kind of plant will thrive in that combination of environmental factors and cultural methods which aids its cells to perform their work at the right times.

When all the conditions for growth are satisfied, the dividing cells will invariably produce new vegetation; when certain elements are either partly lacking or somewhat in excess vegetative growth may be slowed down, and reproductive activities may be increased; and when any essential factor is absent, of too great quantity, strength, and of too long duration, it will become a limiting factor and will harm or kill the protoplasm and, therefore, will injure or kill the plant.

The total amount of vegetative matter that a plant produces depends upon the amount of organic matter, water, and mineral elements which were accumulated and stored. The size and quality of the plant depend upon the number of new cells that were formed, how much they increased in size, and in what proportions they were differentiated into the various tissue systems and organs. From the standpoint of man the yield of a plant does not necessarily depend upon the total quantity of organic matter that is produced, but on the form in which it is accumulated and where it is stored. We want a wheat plant to place most of its food in certain definite layers and proportions in its grains, a sugar cane plant to form a great deal of sugar and store it in its stems, a potato plant to accumulate a large amount of starch in its tubers, and an apple tree to place a certain quantity of nutrients in its fruits, but also to leave a reserve in its stems and roots for future use.

We can divide the life cycle of a plant into several periods or stages which are determined, to a large degree, by the times when the newly formed elongated cells are being differentiated. These periods of differentiation have a direct effect upon the yield because it is then that the tissue systems and organs are being created. If at such a time some inner or outside factor causes an elongated cell that might have been changed into a flowering bud to be transformed into a leaf, the yield will be seriously affected. Therefore, any stage of growth or development that permanently affects the plant is called a critical period. The several critical periods during the growth of a plant are separated by intervals of growth or dormancy during which its development may be more or less retarded or accelerated without influencing the yield to any great extent.

The relationships between the critical periods and yields of plants are variable, depending upon the kind of plant and the region where it is cultivated. The critical periods of most annuals and biennials are relatively simple and fairly well understood, while those existing in herbaceous perennials and in woody, long-lived shrubs and trees are very complicated. A typical annual, such as wheat, experiences six critical

periods during its life cycle. These are, germination; tillerage, or the stage when the main stem forms adventitious buds which will grow into secondary stems; earing, when the floral buds are being formed and developed; pollination; fertilization; and maturation of the grains. It is very difficult to establish all the critical periods of a long-lived woody plant such as an apple tree because the formation of the spurs that will produce the fruits takes place several years prior to bud formation, and depends upon the condition of the tree at that time. In such cases it is only possible to establish such critical periods as bud formation, flowering, pollination, fertilization, fruit set, and maturity.

The needs of a plant vary at different stages of growth, and an optimum condition at one critical period may be a limiting factor at another. Before germination the seeds of many plants require low temperatures, dryness, and darkness, while they must have warmth and moisture when they are ready to germinate. When the growing points are active and vegetative growth is taking place at a rapid pace the plant needs nitrogen, light, warmth, and moisture, while the best seeds are matured during periods of cold and drought.

The best way to find out the needs of a plant at each of its critical growing and dormant periods, and to determine which cultural methods will result in the highest yields by the most economical means, is to grow members of the same clone, strain, or variety in different places under varying conditions. The more factors that can be controlled, the less chance for error. Therefore, the best studies are made by growing plants in artificial cultures under glass, where a great many factors can be controlled.

Some of the most important factors which cultivators who grow their plants outdoors can control to a greater or lesser degree are the fertility of the soil, water, light, heat, wind, weeds, pests, diseases, and the sizes and shapes of their plants. In the use of the various types of equipment, supplies, and cultural methods that are at their disposal, all commercial growers and most amateurs must consider an economical limitation known as the law of diminishing returns, because there is a great deal of difference between maximum production and economic production. For example, if the application of fifty dollars worth of fertilizer increases the value of the crop by one hundred dollars a large profit is realized and the operation is a decided financial success. An outlay of an additional twenty-five dollars for the same crop under the same conditions will not result in a further 100 per cent gain. The percentage of gain will be much smaller, but the increase in outlay may still be worthwhile, especially during those years when the crop commands a high price. A total outlay of a hundred dollars, on the other hand, will increase the value of the yield so little that a financial loss will result.

One of the most essential environmental factors is the soil. A soil is considered to be suitable for plant growth when it is fairly uniform in character, has sufficient depth for normal root growth, is well aerated, has a fair water-holding capacity and good drainage, supplies plants with adequate nutrients, experiences appropriate temperatures, is easily worked, is free from weeds, is properly exposed and not too steep, has a suitable reaction, and contains no injurious factors. Soils differ greatly in these and other characteristics, such as color, texture, structure, number and size of rocks and stones, permeability, and the quantities and kinds of living organisms present in the ground and on the surface.

In nature, the fertility of the soil is maintained by a continuous renewal of organic matter from animal excretions and from dead and decaying living organisms that are broken down into their original elements that can be used again by plants. In addition, the various chemical and biological activities in soils slowly change the locked-up nonsoluble elements into forms available to plants. But when man steps in and cultivates plants, various substances are removed from the soil faster than they can be replaced by natural means. Man is most destructive in stirring the land and in harvesting, both of which accelerate the impoverishment of soils.

Cultivation

In order to cultivate plants man must disturb the upper or surface soil by tillerage operations. By stirring the soil man accelerates the normal geological weathering that has been going on for ages under natural conditions—which is part of the whole soil-forming process (Fig. 182)

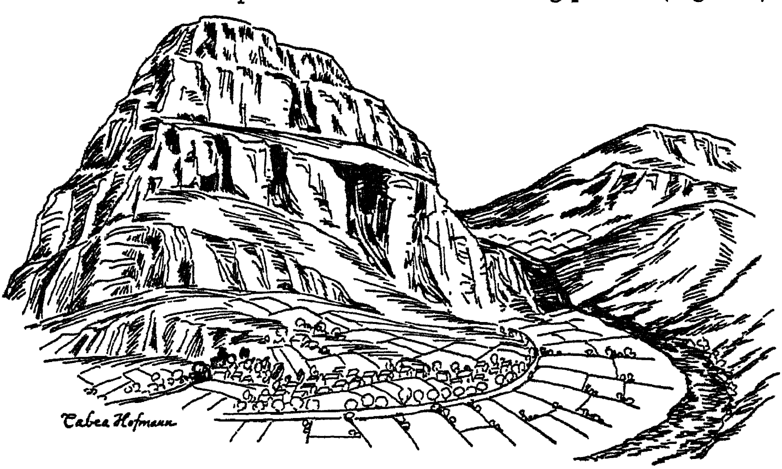

Fig. 182. Soil erosion

—and exposes it to devastatingly rapid gravity, wind, and water erosion which removes in a short time the rich surface layer that took centuries to build up. It has been estimated that a dense cover of vegetation is three hundred times more effective in holding soils, and six times more effective in retaining rainfall, than clean, tilled crops.

When land is cultivated the soil is loosened, and the large air spaces formed permit the rapid entry of large amounts of oxygen. This oxygen accelerates the activities of the bacteria and other soil organisms, which in turn break down organic materials and liberate nutrients essential for plant growth. The soil organisms liberate more carbon dioxide gas, which increases the acidity of the soil solution, making still more nutrients available for plants. Thus fertility of the soil may be increased by tillage. But if the nutrients are liberated at a faster pace than plants can absorb them, the unused vital elements may either be lost forever by being leached down away from the root zone, or they may be locked up by other organisms and chemical actions and become unavailable again. Too great an increase in acidity may likewise be harmful.

There are many ways by which erosion is controlled. Poor land that is very susceptible to devastating surface weathering may be left untouched when its native vegetable cover is adequate and useful as a wood lot or for grazing. When the native vegetation is unsuitable, the land is reforested or planted in various types of grasses, other herbs and shrubs, and changed into permanent wood lots, pastures, or used for the production of hay and other sod crops.

To reduce erosion from fertile hilly or rolling fields that are used for cultivated crops, the land is laid out in contours, and planted and tilled across the slope instead of uphill and downhill (Fig. 181). Water erosion is further controlled by planting land in strips of close-growing soil-retaining sod crops that do not require tillage, alternating with strips of cultivated crops. Two methods used to reduce the harmful effects of winds are either to plant natural barriers in the form of fast growing, tall trees or to erect artificial obstructions or windbreaks.

In certain regions the dangers of water erosion are so great that shallow ditches, diversion channels, and dams are constructed to conduct the excess water off the land slowly. In semi-arid and arid regions where irrigation is practiced or where it is necessary to conserve every drop of natural rainfall on very fertile hills and mountainsides, retaining walls and terraces are built both to hold the rich soils in place and to ensure absorption of all available water. The many benefits derived from terracing fertile soils on hillsides were recognized by the ancients, and the terraces that they built in the Mediterranean regions, India, China, Japan, Peru, and other lands have retained their fertility and are intensively cultivated until this day.

Soil Fertility

Under natural conditions soils retain a balanced proportion of all the soil nutrients that the natural vegetation requires. The vegetation fits the soil, climatic, and other environmental conditions; and the soil, climate, and other environmental factors suit the local vegetation. It is for this reason that we are able to use some wild growing plants as vegetable indicators to tell us what the soil and climatic conditions are like, what kinds of plants may be cultivated, and what types of farming may be practiced in a particular locality. Land that is suitable for grazing may not be good for cultivated crops, and a soil that produces excellent onions may not be appropriate for wheat. Within certain limits the total contents of any one of the soil nutrients in a plant is proportional to the available quantities of that element present in the soil. Oranges grown on one type of soil may be very rich in mineral elements and vitamins while the same variety grown on another kind of soil may be poor in these qualities. A carrot that is produced in a soil that is devoid of iodine will not contain that valuable element. Sometimes the right plants are selected for a given soil; sometimes suitable soils are chosen for certain plants.

When man harvests plants and removes them for his use he also takes away many elements that were present in the soil. Some of these elements occur in such abundance and are made available for plant growth in such balanced regularity that there is no danger of their becoming scarce. Others are either removed in such large quantities or become available so slowly that they must be replaced, or some factor in the soil must be changed so that they may become available as plants need them.

Of the seventy-four elements that have so far been found in various plants at different times, about fourteen or more are essential for plant growth. Their ultimate origin is either the air or the soil. Since most of the substances needed by plants are usually found in sufficient quantities in the air and in the soil, only three are commonly considered fertilizers. These are nitrogen, phosphorus, and potassium. Heavy cropping often exhausts the available supply of these elements in the soil so that it becomes necessary to add one or more of them in order to continue to produce good crops.

Nitrogen is the chief promoter of vegetative growth. Although the air is four-fifths nitrogen, this essential growth element must be fixed in the soil by being combined with another element or elements before it can be absorbed by the feeding roots of plants. The amount of nitrogen present in the soil in an available form varies from hour to hour, day to day, and season to season, and depends upon climatic conditions, the

number and activity of the nitrogen-fixing and liberating soil organisms, the amount of organic matter that is being decomposed, and the quantity of nitrogen that is present in other forms.

In order to replenish the supply of available nitrogen, either organics such as manure, guano, legumes, dried blood, tankage, fish scraps, and cottonseed meal must be incorporated into the soil, or some chemical substance that contains available nitrogen or carries this element in a combination the soil bacteria can change into an available form must be added to the soil.

The amount of nitrogen required depends upon the kind of plant, its state of maturity, and many other factors. Generally, trees, shrubs, and leafy herbs that produce a large amount of vegetation use considerable quantities of nitrogen during their growth periods. A deficiency of available nitrogen results in plants of poor color, appearance, and quality, small leaf surface, and low production. No amount of other available substances will offset the harmful effects caused by lack of nitrogen. A sufficient supply at the right time encourages stem and leaf development; permits plants to form rapid luxurious thrifty growth, and attain a deep green color. This results in healthy plants that are better able to withstand unfavorable conditions, better able to utilize the other nutrient materials, and thus produce large yields. An oversupply of nitrogen tends to cause late maturity, poor seed development, induces plants to be unfruitful and succulent, making them more susceptible to insect and disease attack.

Phosphorus is considered to be the key element to successful farming because the total supply of this essential material is often inadequate. Phosphorus is present in every living cell, and is essential to both plants where it accumulates in their seeds and roots, and animals where it is found together with calcium in bones, horns, teeth, and hoofs. This vital nutrient is generally used by more growers and applied in larger quantities for the production of more crops than any other element. It is so universally used because it favors rapid growth and development, stimulates root growth, hastens fruiting and maturity, and often improves the quality of the seeds, roots, and vegetation in general. By the use of phosphorus farmers are able to bring corn, wheat, and other crops to maturity before frosts arrive in regions where the growing season would otherwise be too short.

In order to become available for plants, phosphorus must be combined by complicated chemical processes with other elements and changed into phosphoric acid. Natural phosphate rock and bone meal are sold either in a raw state or are treated with sulphuric acid and marketed as acid phosphate or superphosphate. The most important organic sources of phosphorus are the bones and other remains of animals which are ground up and sold as bone meal or superphosphate.

Although the quantity of potassium found in most soils is high it is generally present in relatively insoluble compounds. The actual role of potassium is unknown, but it is believed that this element is closely connected with the formation of starch, sugar, acids, juices, and similar compounds in plants. It is often used in fertilizing tuber, root, leguminous, and fruit crops. When potassium is lacking in plants they have a yellowish unhealthy appearance and are susceptible to disease attack. Potassium compounds are found in large quantities in such organic materials as seaweeds, wood ashes, waste molasses, and beet sugar. Potassium chloride or muriate of potash is found in natural deposits in many parts of the world. Potassium sulphate, potassium nitrate, and sulphate of potash-magnesia are some of the most important mineral forms of potassium used as fertilizers.

In everyday language the word "lime" may mean any one of a number of substances which are sometimes used for soil improvement, and liming means the use of some one or more of these materials on the soil. In a strictly technical sense, only calcium oxide or quicklime and calcium hydroxide or slaked lime may be properly spoken of as lime. Gypsum is not considered a liming material, although it does contain the element calcium and is of great value as a soil improver. Generally, most but not all acid soils may be cured by sufficient application of lime. Soils that have sufficient lime but are acid and infertile from other causes may sometimes be neutralized by the application of phosphates, or by chemically removing poisonous aluminum and other harmful substances from the soil. Lime is not a fertilizer but an amendment that usually increases the usefulness of fertilizers, and in turn its value is often enhanced when the soil solution contains the other required elements.

Commercial fertilizers are either prepared and sold separately, or in various mixtures carrying nitrogen, phosphorus, and potassium. Such a mixture is erroneously called a complete fertilizer, but does not contain all the elements in correct proportions for any single crop under all conditions.

To determine with a satisfactory degree of certainty the relative fertility of different soils and the needs for chemical elements of crop plants at various stages of growth has long been the object of soil and plant scientists. The results of most chemical tests, however, are often very unsatisfactory, because the quantity of any element found in the soil does not give the true picture of the amount that is available to a certain plant at a particular time. The surest way to find out what elements are lacking in available forms and the varying amounts that are used by plants at different times is to actually grow the plants in separate plots. One plot is left untreated as a check, and the others receive varying amounts and kinds of fertilizers and organics. That plot which

produces the best crop at the lowest cost shows which treatment should be followed for that particular crop in that locality. The economic use of other operations such as irrigation, drainage, tillage, pruning, thinning, disease and pest control, protection against frost and wind, and the time of harvesting may likewise be tested by following similar procedures.

When to apply a fertilizer depends upon the kind of fertilizer and the crop. So far as the soil is concerned there is little difference except that nitrates and other soluble materials may be leached away by rains or made unavailable by chemical and biological factors if applied at times when plants are unable to absorb them. For the plants it is best to have a sufficient supply of each element in an available form in the soil ready when it is needed. Many kinds of plants can advantageously use much of their required elements during the early stages of their life, or at the beginnings of their growing periods. If the supply is ample at those times little may be needed later. Other plants need a continuous supply of all nutrients.

The organic matter that is present in our soils may be considered our most important natural resource, and our most precious heritage. Without organics land is usually a nonliving, nonproducing layer of inert matter, and just so much sand or ashes. Adequate quantities of organic materials increase the water-holding capacity of soils, make heavy soils lighter and easier to till, help hold light soils together, aid in making mineral elements available and storing them for future use, and provide fuel and food for the myriads of soil organisms that live on organic matter. These living organisms decompose organics, liberate the locked-up elements, and make them available for the use of plants. Therefore, the fertility of most soils is largely dependent upon the amounts and kinds of dead and decaying remains of plants and animals, and the types and quantities of living organisms that are present.

The ancients recognized the values of manures, wood ashes, and other organic wastes, and used these materials long before the dawn of history. The Indians in America learned that by placing a fish in each hill of corn at planting time the yield was increased appreciably. Manures are variable and their values depend, in part, upon the type of animal, its age, activity, and the kind of material it eats.

Many crops are grown expressly for the purpose of improving the soil. Such crops are called green manures and are plowed or dug under in order to increase the amounts of organics in soils. In addition to the benefits derived from the presence of any organic in bulk, green manures prevent erosion, take up available plant foods and prevent their loss through leaching, and bring up elements from the subsoil and deposit them in the surface soil. Furthermore, when their roots decay, the soil

is enriched and made more porous, enabling water and air to penetrate into the subsoil. By this means the unproductive subsoils are weathered and changed into fertile soils.

Many different kinds of plants are used as green manures, the choice depending upon soil, climatic, and economic conditions, and the rotation system that is followed. Legumes are generally preferred because they contain sufficient nitrogen to enable the soil organisms to perform their decomposing work rapidly. In certain cases oats, buckwheat, sorghum, mustard, and other nonleguminous plants are used as green manures because they grow rapidly, may be used between two field crops, are easier and cheaper to grow, or produce a large quantity of organic matter. Whenever nonleguminous crops are used care must be taken to provide sufficient nitrogen in an available form for the soil organisms so that they may decompose the material rapidly. When there is lack of nitrogen, water, warmth, or any other essential needed by the soil organisms, the interred organic matter may remain intact in the soil indefinitely. In certain localities weeds may be permitted to grow as cover crops or green manures. This is a very economic way of providing organics to the soil.

All green manure crops are plowed under when they are in a succulent condition just before, during, or right after they have bloomed.

In order to improve the physical properties of soils without incorporating a great deal of bulk, certain types of plant wastes such as cottonseed meal, dried blood, bone meal, muck, peat, leaves, and moss are used as amendments in preparing special soils for greenhouses, hotbeds, seedbeds, window boxes, pots, flower beds, and for certain kinds of lawns and shrubbery. Many kinds of specially prepared soils are used to stimulate the root development of cuttings, for seedlings and transplanted nursery plants, to provide nutrients that become available slowly, produce suitable conditions for acid- or alkali-loving plants, and for other purposes. In addition organic wastes and used soils are mixed to form composts or to rejuvenate greenhouse, hotbed, and potting soils.

Watering

Like fire, water is an essential servant when it is under control but becomes a devastating master when man is unable to direct its actions. No living organism can exist without water, but when there is too much a great deal of damage results.

When the natural precipitation is either low in quantity or unevenly distributed, vegetation is sparse and semi-arid or arid conditions prevail. In many cases the soils of such localities are very fertile because the leaching down of nutrients is reduced to a minimum, the water table is low, thereby increasing the amount and depth of well-aerated porous

soil, and the quantity of water-soluble nutrients is continually being increased.

When in such areas too much sodium and other salts accumulate on or near the surface, the soil attains an alkali reaction and vegetation is either reduced to alkali-loving plants or is completely absent. Under certain circumstances, when otherwise fertile soils in warm regions can be supplied with an abundance of cheap water, such alkali soils may be reclaimed. Such reclaimed soils often become among the most valuable and fertile producers of abundant fruits, vegetable, flower, alfalfa, cotton, tobacco, and other highly remunerative crops.

Fig. 183. Water cycle

Whenever feasible, and often at tremendous expense, water is brought from streams, lakes, wells, high mountaintops, and other humid regions, sometimes thousands of miles away, and raised hundreds of feet to irrigate fertile soils in warm arid or semi-arid regions, when such localities produce an abundance of vegetation (Fig. 181). A hundred acres of irrigated land in a warm region can feed and support from three to ten times as many people as the same acreage situated in a cool humid locality.

The many benefits derived from a combination of fertile soil, warmth, and an abundant water supply were recognized by the ancients. They established their first civilizations in warm regions along the banks of rivers, near water wells and lakes, or built tremendous systems of aqueducts, canals, pools, and terraces and many kinds of water-lifting devices in order to convey water to their cultivated plants.

Many sciences and some of man's most important measuring, leveling, masonry and other tools, instruments and techniques were discovered, invented, and developed by early irrigation farmers. The early settlers along the banks of the Nile River in Egypt and in the Euphrates-Tigris Valley in Iraq studied and recorded the movements of the

heavenly bodies so that they could predict the seasons when their rivers would overflow and leave deposits of rich alluvial soil on their lands, and when to plant and harvest their crops. We divide the hour into sixty minutes and a minute into sixty seconds because the early Babylonians used sixty as a basic number in dividing the circle formed by the sun's shadow as it went around their obelisks or sundials into time units. The compass was invented by Chinese farmers so that they could tell in which directions to lay out their irrigation canals and fields each season after the floods subsided.

As the soil is a reservoir that holds water needed for plant growth, the cultivator is interested in how much the reservoir will hold, how much water will be removed in a given period of time, and how the supply can be replenished. The water-holding capacity of the soil depends to a great extent upon the depth of the soil. This is determined by the amount of fertile porous material that lies above the water table or some impervious substance such as solid rock, hardpan, or some other material that roots cannot penetrate. There are many ways by which high water tables are lowered, depending upon local physical and economic conditions.

Drainage is the most widely used method of removing excess underground water. This is accomplished by placing tile, stone, and other kinds of porous drains at varying depths and distances so that excess water may flow out underground without causing any damage. In certain regions water is pumped out by mechanical means, and sometimes stored in reservoirs for future use. Some plants such as Eucalyptus trees are efficient natural pumps, and are widely used in reclaiming swamps and draining other wet places.

The amount of water that a soil absorbs and the rate at which it is removed depend upon many additional factors, some of which are the texture and structure of the soil, warmth, amounts and kinds of organic materials, and the types and quantity of vegetation on the surface. All the water that remains between the soil particles after the free water has leached downwards, or has evaporated from the surface, remains more or less in place for many months. The only way this available water can be removed is by being absorbed by the roots of plants. Therefore, one of the best ways to conserve water in the soil is to subdue all unnecessary vegetation before it becomes well established. Eliminating a weed after it has pumped out a considerable quantity of water is like closing the stable door after the horse has been stolen.

In order to prevent surface evaporation and the growth of weeds without resorting to tillage, many kinds of coverings such as straw, hay, moss, composition paper, and other materials are used. Artificial or organic mulches are used extensively in growing pineapples, strawberries, bananas, and other crops. In some cases soils are simply scraped or fire,

salt, certain chemicals, and other means are used to prevent the growth of weeds and to kill harmful vegetation.

The amount of water to apply and the best time to irrigate depend mainly upon cost, type of crop, and climate and soil conditions. Water wets as it goes down; therefore, the more water that is applied the deeper the penetration. Some plants have shallow roots and require frequent light applications, while deep-rooted plants are heavily watered at well-spaced intervals. Certain soil organisms, chemical reactions, and other soil factors require humidity while others are benefited by relatively dry conditions. In order to satisfy the requirements of plants, soil organisms, chemical actions, and other soil factors, it is usually best to space irrigations so that the soil attains relatively dry conditions for short periods without harming vegetation.

Although the application of an appropriate amount of suitable water at the right time is very beneficial, when water is applied at wrong times, when large quantities remain too long on the surface and in the root zone, when water removes required materials and leaches them down, away from the root zone, or if it brings in toxic or other harmful materials, irrigation may be very injurious.

Plants take up a great deal of water when they are actively growing and when the atmospheric conditions are conducive to rapid evaporation. When they are approaching dormancy or maturation, or when the air is humid, water may prove harmful. Under such conditions an application of water may reduce the size, color, texture, and quality of the roots, tubers, stems, leaves, flowers, seeds, and fruits, and in addition cause the plants to be more susceptible to insect and disease attack. If the irrigation water is contaminated with the wastes of certain industrial establishments, borax from laundries, oils, and other harmful ingredients, it may injure both the soil and the plants.

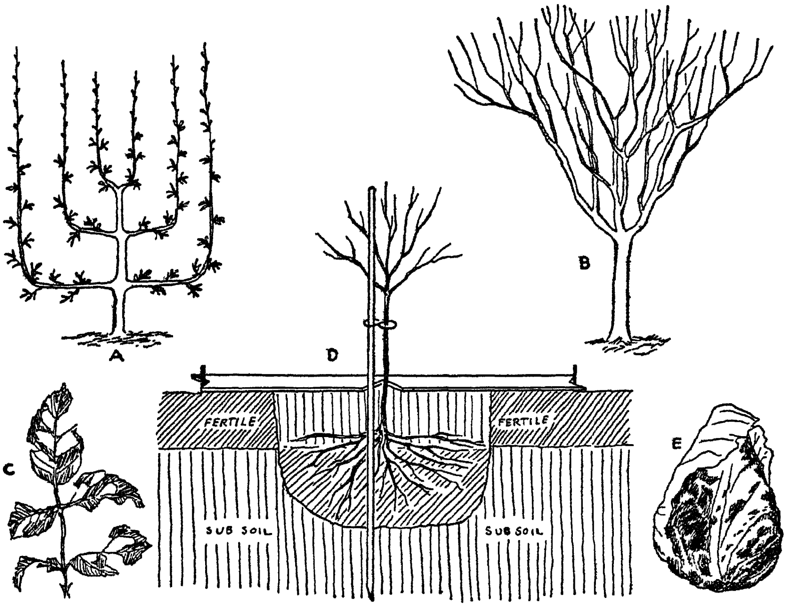

Fig. 184. (a) Dwarf espalier tree, (b) peach tree pruned in shape of a vase, (c) rose leaf destroyed by chewing insect, (d) bacterial rot of cabbage

46. LOCAL ESSENTIALS

IN addition to such fundamentals as stock of good parentage, adequate temperatures during a growing season of proper length, water, drainage, and maintenance of soil fertility which are universally required, certain local essentials such as proper planting, pruning, and protection are necessary in order to grow healthy plants that produce abundant crops and to maintain pleasing ornamentals.

As no amount of care will induce poor seed and planting stock to grow into satisfactory plants, the most important fundamental is to procure certified seeds and sturdy pedigreed plants from reputable dealers, seedsmen, and nurseries. Although seeds may be bought from distant seedsmen, as a rule most plants should come from local nurseries where they grew or were acclimatized to experience approximately the same soil and climatic conditions they will encounter in their permanent place.

Planting

Planting at the proper time is of utmost importance and is governed mainly by the nature of the plant, the length of the growing season, and the duration and severity of drought, frost, and other limiting factors which cause dormancy or death. In those regions where no frost is experienced and water is available the only factors which determine the time of planting are the length-of-day requirements of plants, the season when the plants are dormant, and when the seeds are ready to germinate. Those annuals and biennials which require a short day are grown in the winter and spring; plants which need a long day are grown in the summer and fall; and those which are indifferent may be grown all year round. Although most perennials may be planted whenever they are in a dormant condition, they are usually set out in the spring, early fall, or winter. The time of planting in unirrigated semi-arid regions that do not experience frosts is further affected by the rainy season. In semi-arid regions that experience frost it is essential to plant before frost in the fall or in the spring after the last frost.

In humid regions where frosts are experienced during late fall, winter, and early spring, the temperature and length of the growing season is the main limiting factor. Annuals and perennials that can become well established before frosts occur may be planted in the fall. Fall planting is desirable whenever possible because time is saved, since there is no need to wait for the land to become warm and in a working condition in the spring. In addition the grower is left free to prepare his land and sow the plants which cannot be planted in the fall. Fall planting is sometimes undesirable because alternate thawing and freezing may uproot and kill young plants. Under certain conditions cover crops are planted to offset this harmful factor. Hardy plants that are not susceptible to cold are planted in the early spring, and those which are tender are sown when the soil is warm. Tender tropical plants that require a long growing season are started under glass or indoors during the winter and transplanted outdoors when the soil is in a proper condition to be stirred and all danger of frost is past. Tender plants that require an extremely long growing season but cannot be transplanted or grown in movable containers cannot be grown outdoors in cold regions. As there are early, midseason, and late varieties of many vegetables, proper kinds may be planted at required intervals so that a succession of produce may be grown.

The depth at which most seeds, bulbs, tubers, and root cuttings are usually planted in the field is two to four times their diameter. In general, the drier and lighter the soil, the greater the depth. After the reproductive units are firmly planted, the surface of the soil may be lightly scratched to form a mulch and check surface evaporation. It is of utmost

importance to eliminate weeds as soon as they show above the surface, and to thin the seedlings as soon as they can be recognized. The eliminated seedlings of some plants such as lettuce and beets may be transplanted. The distance apart in the row depends upon the growing habit of the plant and the fertility of the soil. Plants may be placed closer together in poor soils than in fertile lands. The amount of space that is available, the kind of cropping system, and the type of cultivation which will be practiced—whether hand, animal, or machine—are additional factors in determining the distances between rows.

Whenever the soil is fertile and sufficient water is available, every foot of ground may be used to produce profitable plants throughout the entire growing season by the application of a combination of two or more intensive cropping systems. Quick-germinating seeds, such as those of radish plants, may be sown at the same time and in the same row with the seeds of a slow-germinating crop. Such a natural "marker crop" outlines the rows early so that tillage between rows can take place before the weeds can get a start. The quick-growing plants should mature and be ready for removal at the time that the slower-germinating plants are ready to be thinned. Two different kinds of crops may be grown to maturity simultaneously as partners, as in the case of beans or squash with corn, grapefruit with dates, and strawberries with orchard trees. Companion or intercropping is the growing of short-season plants between the plants or rows of a long-season crop, for example, quick-maturing lettuce with slow-growing cabbage. Succession cropping is the following of one crop by another on the same ground in a single season. It is usually undesirable to follow a crop with another of its kind. Instead some unrelated crop should be planted.

By using different cropping systems in combinations as many as three or more crops of vegetables may be grown on the same plot in a single season in monsoon and cool temperate lands. In many tropical and subtropical irrigated regions the land is so efficiently cropped that one acre is made to yield as much produce as could five to twenty acres in cooler locations.

Small herbaceous seedlings and rooted cuttings are sometimes transplanted one or more times after they are removed from the seedbed and before they are placed in their permanent position in the field in order to free the seedbed, prevent crowding, make them more resistant to frost, heat, and drought, reduce the growth of the tap root, induce the formation of many adventitious or secondary roots, and to dwarf plants.

Pruning

Long before man learned how to plant and cultivate his crops he must have noticed that plants shed their leaves from time to time, expelled their unused or mature reproductive organs, and eliminated their super-

fluous bark and dead branches. The art of pruning originated when man discovered that he could cut various plant parts for his use, and remove undesirable organs without causing permanent injury to plants.

Pruning consists of removing or cutting back buds, foliage, twigs, branches, and roots in order to improve the character of the remaining parts, form a strong, evenly balanced, supporting system of branches, eliminate injured, diseased, dead, or otherwise objectionable parts, prevent overcrowding, permit the entry of light and air, eradicate unproductive wood and renew productive wood, establish and maintain a balance between vegetative inclinations and reproductive tendencies, maintain and extend the life of plants beyond their normal span, give a plant a desired size and shape, evenly distribute flowering buds, dwarf plants, reduce evaporation, and for many other reasons.

When wisely performed, pruning contributes materially to the successful establishment and maintenance of plants, but if overdone or otherwise improperly executed it may not only defeat its own ends but injure and kill the plant. It is only the grower himself who is able to select the most desirable pruning system which will be most beneficial to his plants. Some successful growers hardly touch their plants with a pruning knife, while others prune heavily every year. Growers disagree about the importance of this operation and the extent to which it should be performed because constructive pruning consists of much more than the indiscriminate removal of limbs which seem to be in the way, but is a physiological operation which may promote or interfere with the normal and efficient functioning of the different parts of the plant. In pruning it should always be remembered that the nutrients taken up by the roots, and the gases absorbed by the leaves, are combined into food in the foliage and stored in all parts of the plant, and that the removal of any part which contains appreciable amounts of nutrients, and the lack of which greatly disturbs the natural relationship and balance of the root area to the shoot surface, is likely to result in injury to the entire plant.

In order to offset the harmful effects of pruning, many growers pinch off buds and young twigs before they accumulate nutrients and grow. By this means all the vegetation produced is maintained and no loss of food-producing and nutrient-absorbing surface results. By judicious disbudding, the quality, form, and size of the plant and its flowers and fruits are enhanced, and a plant may be trained to grow on wires, frames, and other supports (Fig. 184).

Insects and Diseases

Any internal or environmental factor or condition that causes a disturbance in the normal functioning of any part of a plant, so as to impair its color, size, form, habit of growth and productivity, and deforms,

injures, or destroys its cells, tissues, and organs is a disease-producing agent. For convenience, diseases are grouped into two great classes. Nonparasitic and physiological disorders arise from certain more or less understood unsatisfactory atmospheric, soil, and cultural conditions. They not only occur abundantly in nature, but also by weakening the plant and thus lowering its power of resistance may encourage or permit the entry of parasitic organisms. The second class of disease-causing factors are plant and animal parasites.

Some of the most common and best understood physiological and other nonparasitic disorders are due to such factors as the lack of required nutrients; overabundance of certain elements; presence of excessive soluble salts, acids, radioactive elements, oil, and asphalt in the soil; and illuminating gas, smoke, dust, and sulphur dioxide fumes in the air. In addition insufficiency of air in the soil; too little or too much moisture; abnormally high or low temperatures and pressures; not enough or too much light; and mechanical injuries caused by wind, flood, lightning, fire, gravity, cultural operations, humans, and animals are disease-producing agents.

All plant and animal saprophytes, and those parasites which break down plants and plant parts after they have served their purposes, are vital because they release locked-up elements and energy and make them available for future use. But those which attack growing vegetation and harvested crops are extremely damaging. Although all plant-eating animals are plant parasites, the members of a few genera only are economically harmful to plants and plant products. However, some of these are present in such vast numbers that they cause about two billion dollars' worth of damage annually, and the cost of equipment, supplies, and labor required for protective purposes, to keep them under control and to offset the damage they cause, runs into many additional hundreds of millions of dollars every year. Periodic invasions by mice, locusts, grasshoppers, beetles, lice, aphids, scales, weevils, and other animals devastate large regions sometimes extending hundreds of miles. The spread of the cotton-boll weevil has driven Sea Island cotton production from its former region in Georgia and South Carolina and is responsible for its westward migration to new uninfested lands.

The most destructive animal parasites and pests come from five great groups of animals: protozoa, worms, mollusks, arthropods, and mammals. Some animal protozoa, like their plant bacteria counterparts, are very harmful, while others are highly beneficial. Nematodes, wire worms, and cutworms are among the most destructive members of the vermes or worm group. Of the mollusk group snails and slugs do a great deal of damage to grapes, cabbages, and other horticultural crops. The arthropods in which are included the sow bugs, mites, red spiders, and the enormous number of true insects cause the greatest amount of in-

jury. Such higher animals as gophers, mice, squirrels, rabbits, hares, deer, goats, cattle, and some other mammals live on the bark, succulent stems, leaves, and fruits of many plants. Although crows and a few other kinds of birds may eat grains, berries, and fruits, the damage they cause is usually infinitesimally small in comparison to their greatly beneficial action, devouring large quantities of destructive insects.

The most harmful plant parasites are viruses, bacteria, slime molds, fungi, and a few flowering plants. Little is known about viruses. They are responsible for such diseases as mosaics, infectious chlorosis, and certain yellows, leaf curls, and blotches. Bacteria are sometimes known as germs or microbes and cause such disorders as crown galls, blights, and many rots. Some affect plants through the poisons they release, others by their digestive enzymes. The club root of cabbage and the powdery scab disease of potato tubers are due to slime molds. By far the greatest number of plant diseases are caused by fungi. Just to list them and the diseases they cause would require many pages. Such flowering plants as mistletoe, dodder, broom rape, and cancer root are among the most harmful seed-forming plant parasites.

All remedial measures against disease-producing agents can be classified into three general groups: immunization, control, and destruction. In recent years great strides have been made in selecting, breeding, and propagating varieties of useful plants that are either naturally immune to injurious factors, or can be made resistant by artificial means. Any cultural operation which increases the fertility of the soil and the formation of vigorous, healthy, productive growth helps plants in establishing natural resistance against harmful factors. Any environmental condition or cultural operation which weakens plants, delays maturity, or makes them succulent causes plants to be more susceptible to injurious agents. The placing of young tender plants in cold frames to "harden off" prior to setting them out in the field is a method commonly used to make them more resistant to frost.

Control measures are used to eliminate or reduce the injurious physical conditions and living organisms which cannot be completely or economically eradicated. The successful control of any injurious factor depends mainly upon such preventive and precautionary measures as exclusion, and protection taken sufficiently in advance of the appearance of the trouble. Proper drainage, dams and dikes, windbreaks, outdoor heaters, whitewashing, and shading are some commonly used control measures against harmful physical conditions. Controls against injurious plants and animals include such means as government quarantines; physical barriers in the forms of fences, wire nettings, sticky bands, and coverings; placing alluring traps and poisoned baits, and repelling noisemaking, smoke-forming, waving, shining, and other devices in or near plants. Additional precautions include burning and

burying infected plants and plant parts; removing or interring trash, leaves, and other organic matter; fall plowing; crop rotations; sterilizing soils; making clean cuts during pruning operations, and disinfecting and covering wounds. Furthermore, soils, reproductive units, plants, and farm and garden produce are treated with insect repellents and protectants against diseases. Insect repellents are substances which are used alone or as ingredients in spray mixtures which drive away pests by their disagreeable odor, color, and other characteristics. Tobacco dust is used against aphids, lime against slugs, naphthaline against thripes and household insects, and copper dusts against certain beetles and leaf hoppers. Such fungicides as Bordeaux mixture, coal tar, creosote, and various copper, sulphur, and bitumen compounds are protectants against diseases, and are used as wound and graft dressings and for other purposes.

Those animals and diseases which cannot be completely or economically excluded are destroyed by fire, burial, chemicals in the forms of sprays, dusts, and fumigants, parasites, and by other means. An ideal poison is harmless to all but injurious organisms, and causes little or no damage to the plant or the soil at concentrations sufficient to kill the harmful factors, does not react injuriously when mixed with other chemicals, is stable in shipment and storage, spreads evenly and adheres well to the desired insect or plant, is inexpensive, and easily applied.

Stomach poisons, contact poisons, and fumigants are the three kinds of insecticides that are used to kill animals. Stomach poisons are placed in baits or applied on the plant just before the animal is due to arrive. When the insect or larger animal bites into and chews the bait or plant part it consumes the poison which kills it. Such poisons usually contain arsenic mixed with lead, copper, calcium, and magnesium, or are made from hellebore and other plants that contain substances toxic to animals.

Sucking insects are those which have elongated mouth parts which they inject into the inner tissues of a plant and through which they suck the plant nutrients. Such insects are killed by contact sprays which either enter into the insect through its breathing pores, or clog its pores making it impossible for the insect to breathe. Those sucking insects like aphids, lice, and certain spiders which have soft unprotected bodies are killed by nicotine, sulphur, rotenone, and pyrethrum, while the scales and other sucking insects which are covered by hard shells can be destroyed by oils.

Certain chemicals such as DDT are able to kill both chewing and sucking insects. Such complete insecticides must be used with great care to avoid injury and destruction of bees and other beneficial insects, wild game, domestic animals, and humans.

Many insects work under the surface of the soil or within plants

and therefore cannot be reached by contact or stomach poisons. They are either extracted by wires and other means, or killed by toxic fumes liberated from such substances as hydrocyanic gas, sulphur, nicotine, naphthaline, paradichlorabenzine, calcium cyanide, and carbon bisulphite. Great care must be used in storing and applying such materials because many inflame with ease and all are deadly to humans and domestic animals. In addition to the direct harm they cause, nematodes, flies, mosquitoes, and many other insects are very harmful because they distribute eggs, spores, and other reproductive units of injurious insects and diseases.

Chemicals used to kill fungus growths are called fungicides. They are applied either as eradicants to kill fruiting bodies and feeding tissues, or as protectants which dissolve the germinating spores before they enter the host. Eradicants are usually used to kill the fungus or bacteria existing in the soil, on the seed or other reproductive unit, and rarely on the plant itself. Some of the most commonly used eradicants are formaldehyde, boiling water, steam, and certain mercury, sulphur, and copper compounds.

The time to apply an insecticide or fungicide depends mainly upon the life history of the injurious organism, the state of growth of the host plant, and climatic conditions. Each kind of living organism experiences its particular type of life cycle, and the time of application must coincide with the most vulnerable stage in the life of the insect and fungus growth. Most eggs and spores are well protected with hard covering shells which can be destroyed only by chemicals of such high concentrations that they cause a great deal of injury to plants when applied, while living organisms are generally weakest at birth and in youth. Some eggs and spores are concentrated in groups and can be removed and destroyed with ease; in other organisms the adults can be reached and killed while the other stages in their life cycles are spent underground and in other inaccessible places. Entomologists who study insects, and pathologists who specialize in plant diseases, are continuously adding to our knowledge of the life histories and habits of insects and diseases, and new methods to eradicate those that are injurious.

All repellents and protectants must be present on the plant and in the soil before the harmful organism arrives, while the eradicating and contact chemicals must be applied when the insects and diseases are actually present. If the chemical is applied too soon it may be washed off by rains and its efficiency decreased by the growth of the plant. On the other hand if it is applied too late the damage may already be accomplished and the organism may not be present or in an inaccessible form. Chemicals should be bought from reputable dealers, stored in locked cabinets, handled and used by responsible adults, and the di-

rections on the containers should be scrupulously followed in order to avoid injury to humans, domestic animals, and plants.

It has been recently noticed that certain viruses, bacteria, fungi, insects, and other living organisms have a tendency to mutate with great frequency. It is not as yet known whether the chemicals that are used to eradicate them have an effect upon their reproductive units, or whether their mutations are caused by other factors. Whatever the reason may be, many of the new strains have a tendency to be resistant to established control measures. Therefore, new types of chemicals are constantly being developed and tested to combat them.

Many injurious insects and diseases are attacked and destroyed by other living organisms, which are parasites on them. Biological control is the use by man of natural agencies in his warfare against insects and diseases, in controlling erosion, and for other beneficial purposes. Praying mantises, lady bugs, birds, fish, and other insect parasites are imported, bred, and distributed so that they may destroy harmful organisms. Sod crops and other plants are grown to control erosion, and all cultural operations are accomplished in such a manner as to help nature produce healthy, sturdy, productive plants.

Fig. 185. The elements absorbed by plants are changed into thousands of useful products.

47. THE GOLDEN HARVEST

HARVEST festivals to celebrate the gathering of the year's crop and to observe the Sacraments of the First and Last Fruits with rites in honor of the deity of fruitfulness are among the most ancient of human customs. Isis and his wife Osiris were the gods of fruitfulness and judges of the dead in ancient Egypt. The Hebrews have celebrated the Feast of Tabernacles or Ingathering for thousands of years. Among the gods the ancient Greeks worshiped were Demeter of grain and fertility, Bacchus of wine, Priapus of fruitfulness, Faunus of flocks and wild life, and Pan the pasturer. The English word "cereals" comes from Ceres, the Roman Demeter. Pomona was the Italian goddess of fruits and gardens, and Flora of cereals, grapevines, and flowers. Gouri or Asani in India, Adonis, Attis, and the Grain Mother or Grain Maiden in Europe, the Corn Mother in America, and the Rice Mother in the

East Indies are still worshiped by many peasants in their respective countries. Our day of Thanksgiving, which was initiated by the Pilgrim Fathers in 1621 to celebrate the successful gathering in of the first crops, is one of our national holidays. At that time one of the Pilgrims wrote to a friend in England, saying in part ". . . Our corne did prouve well & God be Praysed we had a good increase of Indian corne, and our Barly indifferent good, but our Pease not worth the gathering . . ." But the scenes of harvest that are pictured in the arts of practically all nations and times are not scenes of festival. They show the harvest as it has always been—hard work spurred by the need to make the most of good weather to get the crop under cover. "Make hay while the sun shines" is a very ancient expression.

The four most important operations connected with the production and distribution of plant products are preparation of the seedbed, planting, harvesting, and transportation. Since the remote time when the first cultivator cleared a piece of ground by fire, dug a hole with a planting stick, harvested the crop with a crude stone sickle, and carried his produce away in a basket, these four vital operations have undergone several great revolutionary changes.

The first great advance in the preparation of a seedbed occurred when the planting stick was turned horizontally and changed into a crude wooden plow that was pulled by humans through the soil, instead of being raised and lowered many times. The second great advance took place when man learned how to harness animals, and used camels, cattle, water buffalo, elephants, and horses to pull his plow. Although the art of iron smelting was known at least as early as 2000 B.C., this metal was too rare and costly to be widely used in the manufacture of agricultural implements until the nineteenth century. The production of farm machines on a large scale did not take place until a practical method of manufacturing cheap steel was discovered in 1825. This sudden improvement in metal machines enabled one person to prepare and plant ten or more times as much ground as one person was able to with a wooden plow. Also, it brought into cultivation forest and other rough lands which could not be cultivated with weak wooden implements. The last great advance took place in 1910, when the internal combustion engine was perfected. By the use of this machine slow animals were replaced by mammoth tractors which can, at a rapid pace, pull more than scores of animals.

No matter how much land a person can prepare, sow, and cultivate, all his efforts in preparing the land, planting seeds of the highest quality, maintaining and increasing soil fertility, and protecting plants and raising bumper crops are wasted, if the crop is not harvested at the right time. The invention of satisfactory harvesting equipment has always lagged behind the perfection of cultivation and other agricultural ma-

chines because of the many complications involved in harvesting crops. Plants as a rule do not mature evenly, and some plant parts, even on the same plant, are ready for harvest earlier than others. It is very difficult to devise a machine which can select and gather certain plant parts without bruising them, and leave others unharmed when they have the same size, form, and texture. Most plant parts are very tender at the moment that they are ready for harvest, and are easily bruised, crushed, punctured, and otherwise injured even when the machine is padded with soft material. One of the main reasons for the extensive production of cereals; dried peas, beans, lentils, and other dormant seeds, nuts, and fruits; and of potatoes and many root crops is that they can withstand rough treatment and, therefore, can readily be harvested and cleaned by machinery. The growth of many delectable crops is restricted, even though they can be preserved with ease, because so much hand labor is required to gather them.

From the time that the sickle was invented in prehistoric times until the advent of the reaper in 1831 and the thresher in 1860 all grain was harvested and winnowed by hand. Since the invention of these harvesting machines extensive fields ranging thousands of acres in area are planted in cereals in many parts of the world.

Until 1765 when a practical steam engine was first used all motive and stationary power was supplied by humans, animals, wind, and water. Since that date, steam, internal combustion, hydraulic and electrical engines have been so well perfected, and so many excellent highways, water ways, harbor installations, and airplane landing fields have been built that tremendous quantities of farm produce may be transported thousands of miles out of formerly inaccessible places. By the use of powerful machinery the products of the farm are converted into innumerable articles.

In harvesting man gathers desirable roots, tubers, stems, buds, leaves, flowers, seeds, fruit, bark, and internal tissues and juices at the time when they contain the maximum amount of produce at the required stage of maturity. From the standpoint of man the state of maturity for harvesting ranges all the way from actively growing, tender, succulent parts, through all stages of dormancy, to fully mature, nonliving, hard dry substances. The time at which a plant will give the largest yield of the highest quality, and the length of time during which the crop will remain at the proper stage for harvesting, varies with the season and kind of plant. Each plant cell, tissue system, and organ has a more or less definite life span during which it is edible and otherwise useful to man. The length of time during which any plant or plant part retains its usefulness depends upon its nature; the stage of development it reached, the climatic conditions it experienced, and the gathering methods employed during harvesting; and the kind of handling it re-

ceived after being uprooted from the soil or separated from the plant.

Produce such as asparagus spears, the buds and leaves of certain plants, and most flowers are at their prime when they are actively growing and their cells are increasing in size at a rapid pace. Their cells have not started to form thick structural walls and protective coverings. Their turgency is due solely to the large amounts of water they contain. As soon as such plant parts are removed they have a tendency to wilt rapidly unless supplied with water. The life processes of some may be somewhat retarded by refrigeration. As their excellence depends upon their succulence they are seldom dried by dehydration, but they may be preserved by being canned or rapidly frozen immediately after being gathered.

Certain fleshy fruits are picked before their seeds are ripe, when their inner tissues are just starting to break down, and their outer skin cells still possess chlorophyll bodies and are deep green in color. Such items as cucumbers, green peppers, string beans, and sweet corn are consumed before ripening. Other plant products must undergo various natural internal breakdown processes or be processed by artificial means before they are made fit to eat or otherwise useful to man. Bananas, lemons, pears, and other fruits ripen while in transit and storage before being consumed. Many fruits that are fit to eat but have not assumed a pleasing outer color are treated with ethylene and other gases, or stored in the dark so that the green chlorophyll disintegrates and the desired color appears. Cabbage, and green olives, cucumbers, and tomatoes are softened by being pickled in brine. Many plant parts are ground, cracked, distilled, concentrated, roasted, boiled, baked, salted, sweetened, and soured by various means. Breadfruit, dates, tea and tobacco leaves, cacao and coffee beans, flax fibers, white pepper, and many other vegetable products are fermented. In addition to being fermented tobacco leaves are smoked. The latex of rubber trees, black pepper, and a great many other plant products are dried by smoke and other means.

Most fleshy fruits are not fit to eat until their seeds have ripened: by then, their internal cells have started to break down; their storage materials have changed from hard starches, alkaloids, tannins, acids, and other unpleasant, often poisonous, substances into desirable products; and their skin cells have lost their unattractive inner or ground-green color and assumed an attractive light green, yellow, orange, red, or blue hue. Some, such as peaches, apples, persimmons, tomatoes, strawberries, and many melons, are picked when they are firm and their outer color is just starting to change. Others such as grapes, raspberries, figs, black olives, watermelons, and most plums must fully ripen on the plant before they can be harvested.

Some fleshy plant parts such as artichoke, cabbage, and broccoli

buds; cauliflower and orchid blossoms; onion bulbs; the rolled foliage of leek and endive stems; celery stalks; rhubarb petioles; parsley, lettuce, and spinach leaves; potato tubers; and the roots of carrots, turnips, beets, and radishes are fit for use as soon as they are formed. Such plant parts may be harvested at any time after they have attained their desirable size, and before they blossom, become tough, or are destroyed by diseases, pests, frost, and other harmful environmental factors.

All so-called "dry" seeds, grains, nuts, and fruits are harvested after they have attained full dormancy. The time of gathering such plant parts is usually very short, as all but corn kernels become separated from the plant and drop to the ground as soon as they become ripe. When properly stored such dormant plant parts are very resistant to unfavorable environmental conditions. They can usually stand a certain amount of rough handling, and when properly stored can be conserved for many years without resorting to artificial preservative means.

Such nonliving parts as heartwood, cork, briar root, cinnamon bark, many fibers, and the outer coverings of certain nuts are impregnated with cellulose, lignin, tannin, resin, wax, and other natural preservatives. When borne on annuals they are gathered when they reach full maturity, before inclement weather and destructive organisms begin to deteriorate them. The fully matured, well-preserved parts of perennials are harvested at any convenient time after they have accumulated a sufficient amount of produce. After being gathered they are separated from undesirable tissues, dried, powdered, or preserved and processed by other means. Certain gums, resins, and other nonliving liquids which contain preservative substances and are not broken down by natural internal processes may be stored for longer or shorter periods of time in their natural state before being processed. Others, such as rubber latex, chicle, and sugar maple sap, must be dried or concentrated by evaporation as protection against fermenting and other destructive organisms.

The gathering of internal juices, roots, bark, wood, buds, leaves, and other nonreproductive parts of living perennials requires special care so that the plants may continue to yield satisfactory crops for many years. Harvesting should not be initiated until the plant has reached maturity, and only a certain percentage of produce may be gathered during a season. If harvesting is started too soon, if too much is removed at one operation, and if cropping is accomplished at too frequent intervals, the plant will be permanently injured and death may result.

The act of removing a living plant part, whether in an active or dormant state, does not kill the cells of the detached organ outright. The cells continue their life activities until they naturally break down by the actions of internal processes, or are destroyed by parasites, fire, frost, pressure, and other unfavorable environmental factors.

The rate at which living parts deteriorate depends upon the actions of their enzymes, the rate of respiration, and other natural, internal, breakdown processes. These are influenced by such conditions as their state of development when gathered, the type and condition of their protective skin cells, and such external factors as light, air, warmth, and moisture. In general, all factors that aid life activities hasten internal breakdowns, and all that exclude air, warmth, moisture, light, and parasitic organisms help in retarding breakdown.

If a living plant organ is unable to obtain oxygen from the surrounding air it may break down its own tissues in order to liberate the necessary amount of oxygen required by its enzymes and other elements. The presence of light induces the formation of green chlorophyll in the skin cells of tubers, bulbs, stems, and certain seeds. Any organ that contains living growing points or cambium dividing cells may grow in storage when conditions for growth are suitable. As a rule those succulent plant parts which contain active cells and have weak and bruised protective coverings are very perishable, while those which are fully mature have sturdy internal tissues, and are protected by efficient unbruised outer coverings impregnated with tannins, waxes, resins, and other conserving materials may retain their texture and form for hundreds, if not thousands, of years when properly harvested and stored.

Skill in determining when a crop is ready for harvest, care in gathering, and the use of proper containers and procedures are of the utmost importance in securing suitable crops. Size, color, texture, and chemical composition are some of the most important characteristics that are used in determining the time when the crop is ready to be harvested. In some cases a representative of the packing house, co-operative, processor, shipper, and dealer tests the produce and determines the time of harvest.

In order to prevent the sale of undesirable produce many crop-producing localities have enacted laws prohibiting the sale of any produce which does not conform to certain standards. In general crops are picked when dry, after the morning dew has evaporated. Many are destroyed if they become wet after being picked. Tender perishable crops are plucked or cut with great care by trained pickers who wear gloves and have short fingernails. Certain fruit and other produce cannot be removed from the field until they have "sweated." These are placed in slatted wooden boxes and left outdoors overnight or for several days until their skins become tough. Some very perishable items are placed directly in the container in which they will be sold.

Conserving the qualities which a crop acquires in the field, enhancing them, and preserving them until they are ready to be used have always occupied the attention of man. Crops that are not sold in the containers in which they are placed in the field may be cleaned, washed, treated

with various chemicals, graded, processed, stored, and repacked several times before they reach the consumer. The dormancy of many plant parts is usually maintained with ease by keeping the produce in a protected, well-aerated, dry, and cool place. When protected from frost, such items as cabbage, turnips, carrots, and beets may be stored underground or in earthen cellars over winter. Many fruits and other fleshy plant parts are conserved for many months in dark, moist, well-ventilated, cool indoor storages. Some plant parts are dried in the sun, by fire, smoke, and other means. A large variety of vegetables and fruits are preserved in airtight jars and cans after they have been scalded and all disease organisms have been killed.

One of the most popular methods of delaying internal breakdown and reducing the action of disease organisms is to cool the products just above freezing and to maintain a low temperature in refrigerators. Many fruits and vegetables are pre-cooled, and shipped thousands of miles in refrigerated freight cars, ships, airplanes, and trucks. The most modern method of maintaining the quality of foods and other organic materials is to freeze them rapidly and to keep them at temperatures well below the freezing point. By this means all living activities are brought to a standstill, and the plant or animal part can be maintained in that condition for many months or years.

Of the approximately 335,000 species of plants known, about 2,300 are exploited by man and used for food, clothing, shelter, implements, and adornment. About 1,000 are used for wood and wood products, 500 for food, 300 are drug plants, 150 are condiments and perfumes, 85 for fibers, 75 for gums, resins, and rubber, 65 supply fats, oils, and waxes, 60 for dyes, 55 for beverages, 20 for tannins, 15 for soaps, and 10 are smoked and chewed. The members of fifty genera of plants occupy over 90 per cent of the annual harvested crop of the world. These include rice, wheat, barley, oats, rye, corn, dried beans, peas and lentils, vegetables, potatoes, hay and forage, wood and wood products, cotton, sugar, fruit, rubber, flax, soy beans, and tobacco.

As the population of the world increases the amount of fertile land surface for each person decreases. Better methods of cultivation must be continuously devised. Nutritionists estimate that two-and-one-half acres are required to provide the minimum diet for one person. Today there are less than two acres available for each person.

Life is one of the mysteries of the universe. One thing we know—remove plant life from the world and there would be no humans and animals. Human cultures and civilizations would disappear. Only rock, dust, and water would remain where man had once roamed and thought.

NOTES ON BOTANICAL AND AGRICULTURAL PUBLICATIONS

As this work deals with a wide variety of subjects, even a shortened comprehensive bibliography should list hundreds of general works and more than one hundred publications for each chapter in the English, French, German, Spanish, and Russian languages. Because of the restricted space available for a bibliography, only some of the most important institutions that publish semitechnical and popular articles, periodicals, bulletins, and books in the English language can be mentioned.

The Agricultural Index, published by H. W. Wilson Company, New York, N. Y., lists the commercial book companies and other institutions that publish works in the botanical, biological, agricultural, and related sciences.

The publications' secretaries of the following institutions will gladly answer any inquiries relating to their publications: The United States Government Printing Office, Washington, D. C.; The United States Departments of Agriculture, Interior, and Commerce; the several state agricultural colleges and experiment stations; the presses of Columbia, Harvard, Pennsylvania, Syracuse, Princeton, and Yale Universities in the United States, and Oxford and Cambridge Universities in England; The Smithsonian Institute, Washington, D. C.; The Carnegie Institute, Washington, D. C.; The National Geographic Society, Washington, D. C.; Boyce Thomson Institute of Plant Research Inc., Yonkers, N. Y.; The Museum of Natural History, New York, N. Y.; Chicago Natural History Museum, Chicago, Ill.; Brooklyn Botanic Gardens, Brooklyn, N. Y.; Missouri Botanical Gardens, St. Louis, Mo.; Arnold Arboretum of Harvard University, Jamaica Plain, Boston, Mass.; Royal Botanical Gardens, Kew, England; Rothemstead Experiment Station, Haperden, England; National Council of State Garden Clubs Inc., New York, N. Y.; American Horticultural Society, Washington, D. C.; Audubon Society, New York, N. Y.; American Garden Guild, New York, N. Y.; the several state and local agricultural and horticultural societies.

Several daily and Sunday newspapers, and some newspaper syndicates, have garden or farm editors and publish illustrated popular articles of local interest.

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